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STUDIES ON THE MOISTURE EQUIVALENT OF SOILS[1]

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University of Nebraska

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The moisture equivalent centrifuge is now a recognized piece of apparatus in well equipped soil physics laboratories, and the moisture equivalent is generally accepted by American soil scientists as one of the physical constants of soil. When the determination was first proposed by Briggs and McLane, of the Bureau of Soils, in 1907, it was hoped that it could be used as a single valued expression of texture, and as an index of the field-carrying or water-retaining capacity of the soil. Briggs and Shantz (5) have published formulas showing its simple relations to the hygroscopic coefficient, wilting coefficient, maximum water capactiy, and mechanical analysis. Alway and Russel (2) and later Russel (8) failed to find that its relation to the hygroscopic coefficient was sufficiently constant to make it of value in indirect calculation of the latter, except in local studies where the ratio might be determined for the soil type in question. Several different formulas showing the relation of the moisture equivalent to mechanical analysis have been derived by Alway and Russel (2), Smith (9) and Middleton (7), which differ from the one of Briggs and Shantz. No one formula seems best for all soils, and one may question if the moisture equivalent is a reliable index of texture. Alway and McDole (1) and Israelsen (6) have presented data to show that the moisture equivalent is a close index of the field-carrying or water-retaining capacity of some soils. The work of Alway and McDole (1, p. 49, 65) indicates that the moisture equivalent of coarse-textured soils is much lower and the moisture equivalent of fine-textured soils is higher than their field-moisture-carrying capacity.

In their first publication, Briggs and McLane (3, p. 5), define the moisture equivalent as "the percentage of water retained by a soil when the moisture content is reduced by a constant centrifugal force until it is brought into a state of capillary equilibrium with the applied force." At the time, in the bulk of their determinations, they used a centrifugal force of 2940 times the value of gravity developed by 5000 revolutions per minute on a centrifuge which they had constructed; a period of centrifuging of 30 minutes; and an amount of soil making a layer about 5 mm. deep in the centrifugal cup. In their second publication (4) they have recommended a centrifugal force of 1000 times gravity, developed by a speed of 2440 revolutions per minute

[1] Published with the approval of the Director as Paper No. 3. Journal Series, Nebraska Agricultural Experiment Station, Lincoln, Nebraska.

on the present standardized type of centrifuge; a period of 40 minutes; and a layer of soil 10 mm. deep. In this publication they give in detail the procedure for making the determinations.

The reason for adopting 1000 times the value of gravity as the constant centrifugal force is not clear. There was nothing in the first studies on the subject against its adoption, 1000 *g* is an easily remembered figure and, furthermore, any higher speed may be impractical from the standpoint of mechanical safety. From the argument of Briggs and McLane (3) it would seem that any centrifugal force sufficient to remove the water in the larger capillary spaces might be adopted as the standard centrifugal force just as well as 1000 *g*. Briggs and McLane have already studied at length the factors involved in the moisture-equivalent determination, in particular the effect of speeds developing rather high centrifugal forces. However, in view of the present status of the moisture equivalent it occurred to us that a study of the moisture equivalent of soils under various centrifugal forces below 1000 *g*, together with the studies of Briggs and McLane, might lead to the recognition of a less empyrical definition of the moisture equivalent which would give results more closely related to the texture and to the other soil constants and make the moisture equivalent a more widely used determination.

EXPERIMENTAL

The latest model of the moisture-equivalent machine is splendidly adapted to studies of the speed factor in the moisture equivalent when low speeds are required. It operates on an alternating current, and the speed is kept constant by means of a sturdy, yet delicately adjusted governor that makes and breaks a battery circuit thru a simple relay. The relay throws in and out of the line circuit a delicate rheostat. Very constant speeds are obtainable, and no trouble is found in getting the machine to run at speeds as low as 750 revolutions per minute and as high as 3000 revolutions per minute, which were the highest speeds attempted. The drum of this machine is identical in dimensions with that of earlier models.

From several soil regions 16 soils of widely differing character, were selected for study (table 1). The moisture equivalents were determined by a procedure slightly different from that prescribed by Briggs and McLane (4). The pans were fitted with squares of muslin, instead of filter paper and the proper amount of soil to give a 10-mm. layer after centrifuging was weighed—not measured—into them. After the layer of soil had been carefully leveled off, the pans were stood in distilled water and allowed to saturate from below; then removed and placed on a small square of blotting paper in a tray, covered over to prevent evaporation, and allowed to temper for 18 hours. An 18-hour period of tempering, instead of 24 hours as Briggs and McLane suggest, is convenient, for it allows the centrifuging in a forenoon of the soil put to temper the afternoon before. The above procedure was developed at the Minnesota Experiment Station under the direction of Dr. F. J. Alway, and has been found to

give the same results as that of Briggs and McLane. After the pans were placed in the centrifuge the drum was packed full of cotton to prevent circulation, inside the drum, of air which might dry out the soils considerably in 40 minutes. However, the cotton has never seemed to be of much value

TABLE 1

Description and physical properties of the soils used in this study

SOIL	DESCRIPTION	HYGROSCOPIC COEFFICIENT	MOISTURE EQUIVALENT	MAXIMUM WATER CAPACITY	MECHANICAL ANALYSIS						
					Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Clay
A	Sandy subsoil from the Sand Hills, Valentine, Nebr.	1.67	3.9	29.2	0.5	10.6	28.3	48.6	7.1	1.3	3.6
B	Residual sandy surface soil from near Lincoln, Nebr.	2.63	7.3	30.6	0.3	7.9	20.1	41.5	12.8	9.6	7.8
C	Alluvial very fine sandy subsoil from near Grand Island, Nebr.	3.03	7.3	36.3	1.4	5.6	7.5	32.5	44.0	5.7	3.3
D	Alluvial very fine sandy surface from Missouri River bottom	3.03	7.4	39.7	0.0	0.1	0.5	46.4	41.8	5.8	5.5
E	Alluvial very fine sandy loam surface near Grand Island, Nebr.	6.40	16.8	56.7	0.1	1.5	3.1	13.2	56.7	18.6	6.8
F	Very fine sandy loam surface from southwestern Nebr.	7.40	17.4	49.5	5.4	6.4	5.3	14.2	35.6	17.8	15.4
G	Residual virgin loam surface from Reno County, Kansas	8.30	23.1	69.3	0.0	0.0	0.7	6.7	41.8	31.1	19.4
H	Glacial drift virgin loam surface from Otoe Co., Nebr.	8.70	23.0	67.6	1.2	6.3	7.3	15.4	19.7	29.1	20.9
I	Alluvial very fine sandy loam surface from Scottsbluff, Nebr.	9.50	21.9	62.7	0.5	3.2	3.7	13.1	45.1	20.4	14.2
J	Glacial drift virgin clay loam surface near Lincoln, Nebr.	9.80	23.8	62.8	Tr.	1.1	1.9	9.7	26.3	37.5	23.5
K	Rich alluvial silty clay loam surface near Lincoln, Nebr.	10.20	28.8	70.0	0.0	Tr.	0.3	1.1	19.2	52.3	27.1
L	Glacial drift clay loam surface from Agronomy Farm	10.40	27.0	67.2	0.0	Tr.	0.3	0.5	26.6	41.8	30.8
M	Loessial clay loam surface from Cass Co., Nebr.	11.20	27.5	66.3	0.0	0.0	0.2	0.9	33.3	35.2	30.4
N	Clay subsoil of L—fourth and fifth feet	12.70	30.0	68.6	0.0	Tr.	0.2	0.4	21.9	44.6	32.9
O	Tight clay subsoil of L—second foot	14.70	32.9	67.5	0.0	0.0	Tr.	0.4	19.4	36.9	43.2
P	"Gumbo" from Missouri River bottom, Burt Co., Nebr., third foot	19.80	45.2	89.4	0.0	0.9	0.4	0.9	6.3	31.2	60.3

in this respect. The period of centrifuging desired was timed from the instant that the machine had reached the speed for which it was adjusted.

The effect of speed on the moisture equivalent was studied on the soils in two sets of 8 soils each, designated hereafter as sets 1 and 2.

The determinations were made in duplicate. In case duplicates did not check, the entire set was repeated. The speed was determined by a speed indicator held on the shaft for 3-minute periods, at least three times during the run. If for any reason the speed was not satisfactorily constant, the results were discarded.

Determinations were made at 9 different speeds, developing centrifugal forces from 100 *g* to 1435 *g* in set 1, and at 5 different speeds developing centrifugal forces from 100 *g* to 1330 *g* in set 2. The data are presented in tabular form in table 2 and in graphic form in figures 1 and 2.

TABLE 2

Moisture equivalent of soils determined at different speeds

SPEED	CENTRIFUGAL FORCE	MOISTURE EQUIVALENT OF SOILS OF SET 1							
		B	C	E	J	K	L	N	O
r.p.m.	*times g*								
0	1	30.6	36.3	56.7	62.8	70.0	67.2	68.6	67.5
778	102	17.3	25.2	40.0	40.8	47.0	44.8	45.5	47.5
1230	254	12.5	15.3	30.2	34.5	40.7	38.5	39.2	41.6
1920	620	9.2	8.7	19.6	26.5	32.0	30.2	33.1	35.8
1985	660	8.8	8.7	19.4	26.2	31.3	29.7	32.2	34.8
2185	800	8.3	8.4	18.2	25.8	30.6	28.6	31.5	34.0
2250	850	7.9	8.1	18.1	24.9	30.0	28.3	31.2	33.9
2410	975	7.9	7.6	17.0	24.0	29.4	27.4	30.7	33.1
2710	1235	6.9	6.8	15.7	22.6	26.7	25.5	28.6	31.9
2925	1435	5.9	6.8	14.5	21.9	26.3	24.4	28.0	31.1
		MOISTURE EQUIVALENT OF SOILS OF SET 2							
		A	D	F	G	H	I	M	P
0	1	29.2	39.7	49.5	69.3	67.6	62.7	66.3	89.4
765	98	12.9	26.8	36.7	47.1	43.1	40.4	45.7	61.0
1216	248	6.5	15.1	27.1	35.8	32.6	31.5	37.7	53.0
1810	551	4.4	9.7	21.7	28.5	27.4	26.2	31.7	49.1
2470	1020	3.9	7.0	17.4	23.0	23.1	21.8	27.4	51.2
2817	1330	3.6	7.0	16.3	21.7	21.4	20.4	26.3	49.0

With all soils but one, the determinations coincide closely with a smooth curve of a parabolic type. The one exception is soil P, a very heavy clay that gives abnormally high moisture equivalents at high speeds. The cause of this is undoubtedly the puddling produced by pressure against the bottom of the cup which prevents the escape of the water. On one occasion, free water remained on top of the soil layer after centrifuging.

In the figures the curves have been projected back to cut the ordinate of 0 centrifugal force at the maximum water capacity (Hilgard's). That portion of the curve, at centrifugal forces greater than 100 *g*, can be expressed by the

equation $M = \frac{K}{G^n}$ where M is the moisture equivalent at the multiple of gravity and n and K are characteristic constants.

Table 3 gives the approximate values of n and K for the different soils, and shows the departure of moisture equivalents calculated by formula from

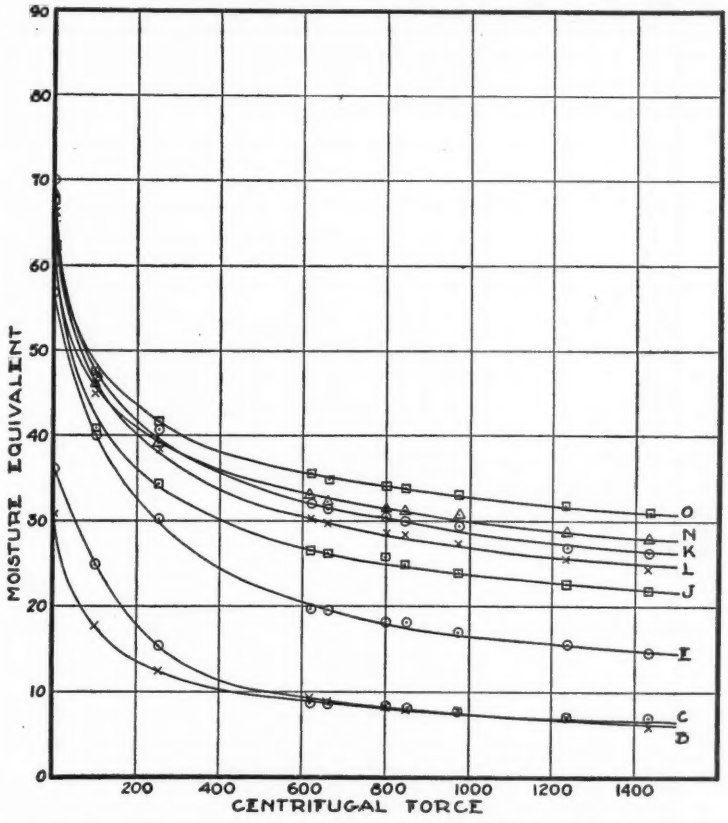


FIG. 1. RELATION OF MOISTURE EQUIVALENT TO CENTRIFUGAL FORCE FOR EIGHT SOILS, COMPRISING SET 1

the values actually observed as 5 different centrifugal forces. Owing to uncertainty as to the direction of the curve for soil P, the values of n and K have not been calculated for that soil. There is a very close agreement between the observed and calculated moisture equivalents at forces greater than 100 g. This agreement is sufficiently close in all cases at 1000 and 1400 g

to allow the use of calculated values at 2000 *g* without reservation in the discussion to follow later.

Briggs and McLane (3) concluded from studies on a number of soils at speeds developing centrifugal forces from 857 to 3554 *g*, that the relationship between the moisture equivalent and the centrifugal force is linear, and that the graphs of this relation for different soils do not meet in a point on the

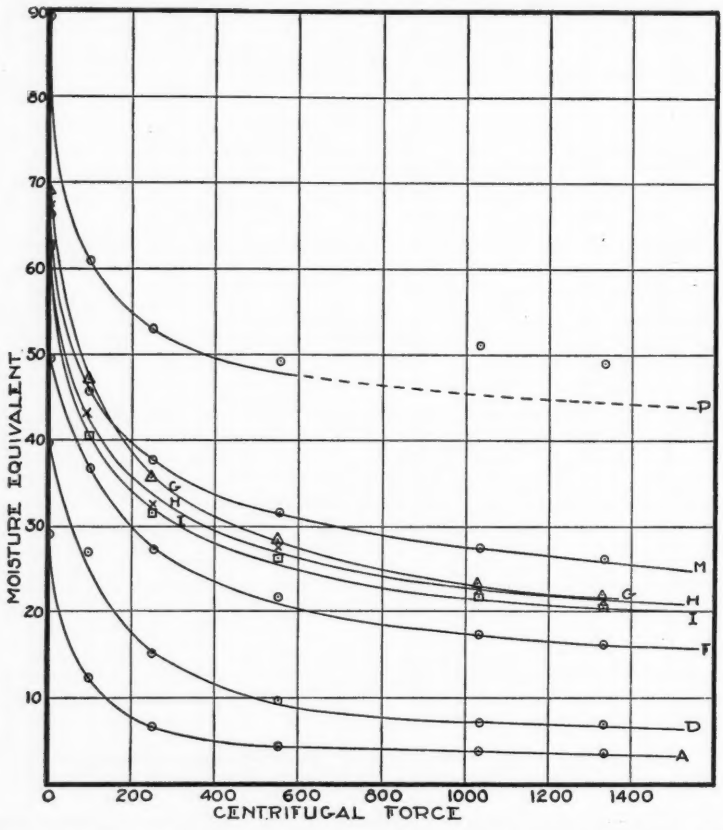


FIG. 2. RELATION OF MOISTURE EQUIVALENT TO CENTRIFUGAL FORCE FOR EIGHT SOILS COMPRISING SET 2

axis, but "the slope of the graphs is in nearly every case the same."[2] The same conclusion could be drawn from a study in figures 1 and 2 of that portion of the graphs beyond 800 *g*, were it not obvious that the graphs below 800 *g*

[2] Briggs and McLane have plotted the moisture equivalent against the reciprocal of the centrifugal force, which makes such a conclusion more striking than in our graphs in figures .1 and 2.

are not straight lines but curves. In figure 3 the data obtained by Briggs and McLane (3, p. 11) for two soils on which determinations of the moisture equivalent have been made at several widely varying centrifugal forces, and the data for soils D, E, and F, of comparable texture have been brought together. It is obvious that the curves obtained by them are of the same type as those of soils D, E, and F, and had they employed centrifugal forces lower than 800 *g* their graphs would undoubtedly have shown curvature.

In studying the effect of low speeds on the moisture equivalent the question will arise whether the moisture has been brought to equilibrium with the centrifugal force in the arbitrarily chosen period of 40 minutes. Figure 4 shows the results obtained in centrifuging 4 soils for 20 and 40 minutes at

TABLE 3

Values of n and K and departure of the calculated from the observed moisture equivalents at various centrifugal forces employed

SOIL	*n*	*K*	CENTRIFUGAL FORCE				
			100 *g*	250 *g*	600 *g*	1000 *g*	1400 *g*
A†	0.364	46.9	−4.1	−0.2	0.3	−0.1	−0.2
B*	0.417	128.2	1.3	0.2	−0.4	−0.7	0.3
C*	0.527	278.0	−0.9	−0.2	−0.7	−0.2	−0.8
D†	0.527	288.4	−0.8	0.7	0.7	0.5	−0.4
E*	0.417	298.5	3.4	−0.5	0.9	−0.1	−0.1
F†	0.336	178.2	1.5	0.9	−0.3	0.0	−0.4
G†	0.303	190.6	0.3	0.0	−0.3	0.4	−0.1
H†	0.270	149.3	0.2	1.1	−0.2	0.0	0.0
I†	0.264	136.8	0.4	0.5	−0.3	0.1	0.1
J*	0.257	140.0	1.8	−0.7	0.3	−0.1	−0.3
K*	0.238	147.9	2.2	−1.1	0.0	−0.7	0.0
L*	0.241	142.2	1.9	−1.0	−0.1	−0.3	0.3
M†	0.228	131.8	0.7	−0.2	−0.4	−0.2	−0.7
N*	0.193	113.8	1.2	−0.1	−0.2	−0.5	0.0
O*	0.167	105.5	1.2	0.3	0.3	0.3	0.3

* Soils of set 1. Actual centrifugal forces 102, 254, 620, 975, and 1435 *g*.

† Soils of set 2. Actual centrifugal forces 98, 248, 551, 1020 and 1330 *g*.

250 *g* and at 10, 20, 40, and 80 minutes at 1000 *g*. It is to be seen that the bulk of the water is thrown out in the first 10 minutes, but the soils continue to lose water for some reason as long as they are centrifuged. After 20 minutes the loss becomes proportional to the time and is the same for all soils at both gravities employed. The graphs are all parallel straight lines and have a slope corresponding to about 0.6 per cent loss per 20 minute interval.

Thomas (10, p. 429) has pointed out that the magnitude of the moisture equivalent of a soil is considerably affected by the depth of the soil layer in the cup. On first thought it would seem that the depth of the soil layer is an insignificant detail in the procedure which might, if anything, raise the moisture equivalent if a layer of soil deeper than 10 mm. is used, because the

center of mass of the soil is brought closer to the center of the drum, and because the deeper layer might interfere with the free escape of the water. Thomas found it to work otherwise and data presented in figure 5 substantiated his findings.

Four depths of a soil were centrifuged at one time so that the speed factor would be the same for all. The centrifugal force used was 1000 *g*, and the period 40 minutes. The 8 soils used were those comprising set 1, on which the data in figure 1 were obtained. With one sandy soil the same results were obtained at all depths, but in all other cases a half depth (0.5*x* gm.) gave a higher result and a depth and a half (1.5*x* gm.) a lower result than was obtained with the normal depth (*x* gm.). With soil O, the heaviest

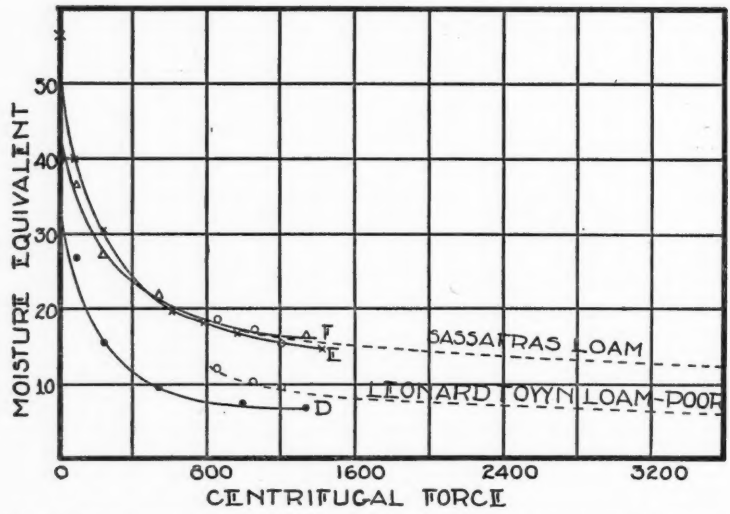


FIG. 3. CORRELATION OF DATA FOR THREE SOILS WITH DATA OBTAINED BY BRIGGS AND MCLANE ON TWO SOILS

soil of the set, the double depth (2*x* gm.) gave the highest moisture equivalent. This is due undoubtedly to the incomplete escape of water thru the deep layer of soil.

Throughout the studies on the effect of speed the same weight of a soil was always used, but unfortunately the quantity was not adjusted to give an exact 10 mm. layer in the soils of set 1. The importance of the depth being then discovered all soil layers in set 2 were adjusted to 10 mm. A variation of 2 mm. either side of 10 mm. affects the moisture equivalent at 1000 *g* by about 1 per cent. The fact that the depth used in the case of soils N, O, and B departed this widely from 10 mm. has not affected the conclusions drawn on the study of speed, rather it leads to the idea that had

some other depth of soil layer been decided upon, one would have arrived at the same conclusions.

DISCUSSION

It is the purpose of this study to determine if the present arbitrarily adopted definition of the moisture equivalent is the one which will lead to the simplest and most constant relations with the other soil properties. The question is proposed why a centrifugal force of 1000 *g* is better than any other; why the depth of the soil layer should be 10 mm.; why the period of centrifuging should be 40 minutes; and what will be the effect on the relations to the other soil properties if one or all of these arbitrary conditions are altered?

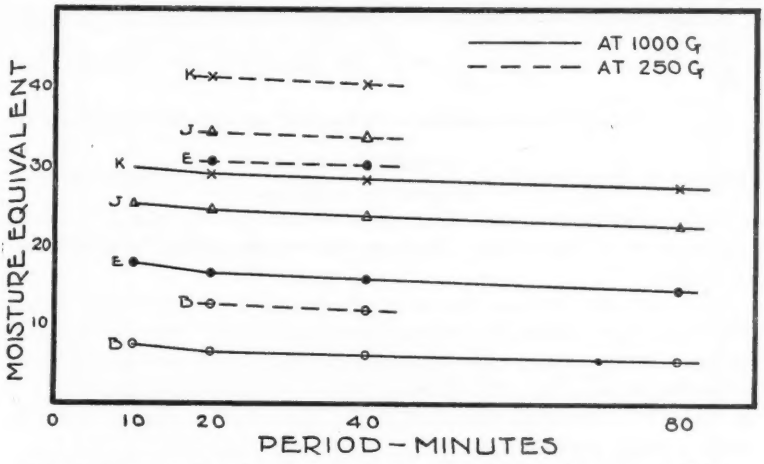
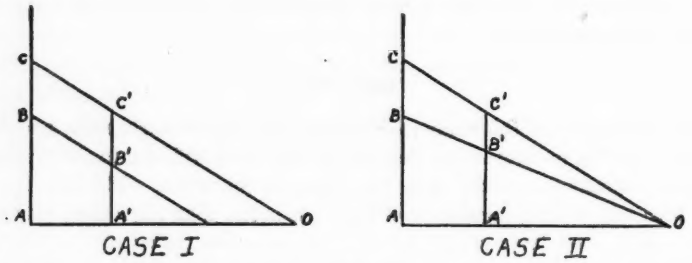


FIG. 4. EFFECT OF PERIOD OF CENTRIFUGING ON THE MOISTURE EQUIVALENT AT TWO CENTRIFUGAL FORCES

The Relation of the Moisture Equivalent to the Hygroscopic Coefficient at Different Multiples of Gravity

According to Briggs and Shantz (5) the relation of the moisture equivalent, determined at 1000 *g*, to the hygroscopic coefficient is linear, and the ratio of the former to the latter is an experimental constant having the value of 2.71. A consideration of figures 1 and 2 shows that the lower legs of the curves which are nearly straight lines are nearly parallel. This is in agreement with the observations of Briggs and McLane. If this be the rule, an ideal constant relation between moisture equivalent and hygroscopic coefficient for all soils is not to be expected. For a mathematical constancy is only possible when the graphs meet at a point, as is plain from the geometrical diagrams and argument following.



Let ab and ac be the moisture equivalents of two soils at the centrifugal force a, and $a'b'$ and $a'c'$ be the moisture equivalents at the centrifugal force a', and let H and H' be the respective hygroscopic coefficients of the two soils. If $\frac{ab}{H} = \frac{ac}{H'} = K$, and $\frac{a'b'}{H} = \frac{a'c'}{H'} = K'$ (by hypothesis), then it follows that $\frac{ab}{ac} = \frac{a'b'}{a'c'}$. Now the latter equality is not true in Case I, but is true in Case II. Therefore the hypothesis that $\frac{\text{moisture equivalent}}{\text{hygroscopic coefficient}}$ = a constant, is verified only when experimental data are in agreement with Case II and since data agree with Case I only, the hypothesis seems without mathematical foundation.

Any correlation between the moisture equivalent and the hygroscopic coefficient at any arbitrarily assigned centrifugal force is either an intricate mathematical one or an experimental one in which a considerable element of probability is involved. The question arises, at which centrifugal force is the ratio of the moisture equivalent to the hygroscopic coefficient the most nearly a simple constant?

Table 4 gives the relation of the moisture equivalent to the hygroscopic coefficient at centrifugal forces from 250 to 2000 g, assuming the relation to be a simple ratio. The values of the moisture equivalents shown in the table are taken from the curves in figures 1 and 2, and are not actual determinations since they were made in two sets not strictly comparable with respect to centrifugal force. The moisture equivalent at 2000 g is calculated by formula. It is obvious that the ratio of the moisture equivalent to the hygroscopic coefficient is not a constant at 250 or 500 g but approaches a constant at 1000 g. The standard deviation and coefficient of variation have been calculated. These both decrease as the centrifugal force increases, and at 1000 and 1500 g are practically the same.

The development of the relation between the moisture equivalent and the hygroscopic coefficient is seen in a study of figures 6 and 7, where the maximum water capacity at 1 g and the moisture equivalents determined at 100, 250, 500, 1000, and 1500 g have been plotted against the hygroscopic coefficient. The curves have been fitted by the star-point method and not by the method

of least squares. The graphs are all parabolas, of the general type $y = a + bx + cx^2$. They begin at a point above the origin in the case of the maximum

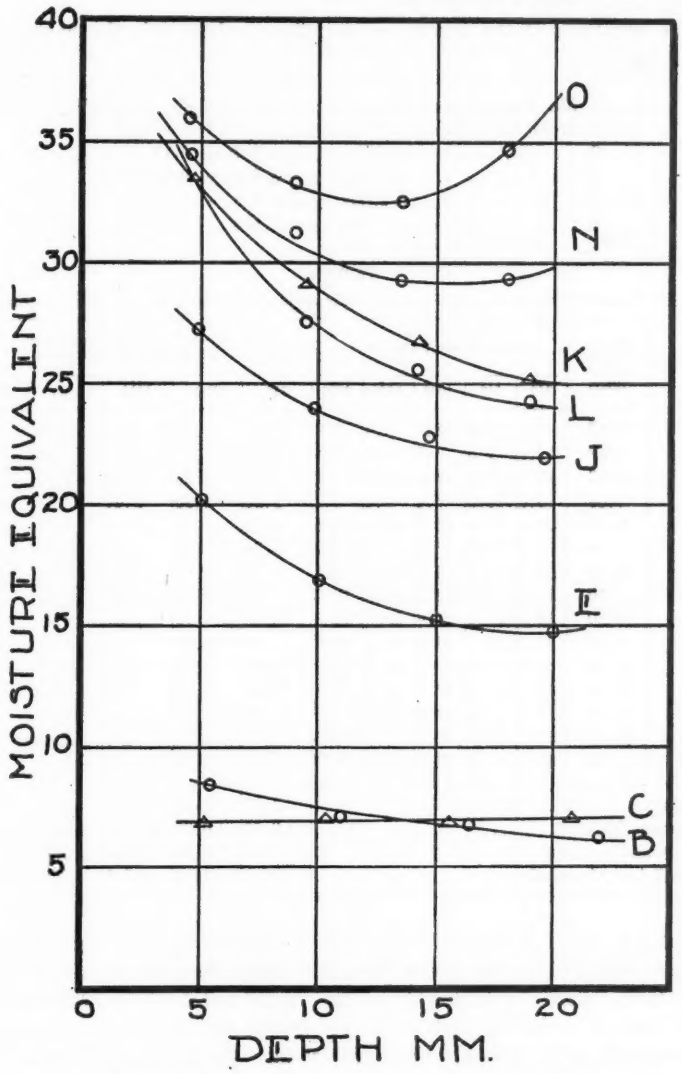


FIG. 5. EFFECT OF DEPTH OF SOIL LAYER ON THE MOISTURE EQUIVALENT

water capacity and the moisture equivalent at 100 *g*, and at the origin in the other cases, and flatten out as the centrifugal force is increased. That

is, a and c approach zero. At 1500 g the graph is practically a straight line, and the equation is of the linear type, $y = bx$. At 1000 g the graph does not depart widely from a striaght line.

The equations of the curves are as follows, where x is the hygroscopic coefficient:

1. Maximum water capacity. $y = 20 + 5.6\ x - 0.115\ x^2$
2. Moisture equivalent at 100 g. $y = 8 + 5.1\ x - 0.13\ x^2$
3. .....at 250 g. $y = 4.9\ x - 0.12\ x^2$
4. .....at 500 g. $y = 3.6\ x - 0.06\ x^2$
5. .....at 1000 g. $y = 2.97\ x - 0.43\ x^2$
6. .....at 1500 g. $y = 2.24\ x$

TABLE 4

Ratio of moisture equivalent to the hygroscopic coefficient at different multiples of gravity

SOIL	HYGROSCOPIC COEFFICIENT	MOISTURE EQUIVALENTS					RATIO—MOISTURE EQUIVALENT TO HYGROSCOPIC COEFFICIENT				
		250	500	1000	1500	2000	250	500	1000	1500	2000
A	1.67	6.5	4.4	3.9	3.4	2.9	3.89	2.63	2.34	2.04	1.74
B	2.63	12.9	9.5	7.3	6.0	5.4	4.90	3.61	2.78	2.28	2.05
C	3.03	15.4	10.0	7.3	6.0	5.1	5.08	3.30	2.41	1.98	1.68
D	3.03	16.0	10.0	7.4	6.6	5.2	5.28	3.30	2.44	2.18	1.72
E	6.40	30.2	21.9	16.8	14.5	12.5	4.72	3.40	2.63	2.27	1.95
F	7.40	27.7	21.9	17.4	16.0	13.9	3.74	2.96	2.35	2.16	1.88
G	8.30	35.9	29.1	23.1	21.0	19.1	4.33	3.51	2.78	2.53	2.30
H	8.70	33.9	27.7	23.0	21.0	19.2	3.90	3.18	2.64	2.41	2.21
I	9.50	32.1	26.2	21.9	20.0	18.3	3.38	2.76	2.31	2.11	1.93
J	9.80	34.0	28.1	23.8	21.7	19.9	3.47	2.87	2.43	2.21	2.03
K	10.20	40.1	33.8	28.8	26.0	24.2	3.93	3.31	2.82	2.55	2.37
L	10.40	37.9	31.6	27.0	24.3	22.8	3.64	3.04	2.60	2.34	2.19
M	11.20	37.7	32.0	27.5	25.0	23.3	3.37	2.86	2.46	2.23	2.08
N	12.70	39.2	34.3	30.0	27.7	26.3	3.09	2.70	2.36	2.18	2.07
O	14.70	41.7	36.9	32.9	31.1	29.4	2.84	2.51	2.24	2.12	2.00
Mean							3.97	3.06	2.51	2.24	2.01
Average deviation							±0.53	±0.29	±0.16	±0.13	±0.16
Standard deviation							±0.67	±0.34	±0.19	±0.17	±0.21
Coefficient of variation							±16.9	±11.1	±7.2	±7.6	±10.5

Table 5 shows the deviation from the determined moisture equivalents of values calculated by the above formula. While the average and standard deviations decrease considerably as the centrifugal force is increased, the coefficient of variation, that is the percentage variation from the average determined value, is nearly the same for all. Furthermore the deviations are systematic, large positive or negative deviations at the maximum water capacity, generally changing to smaller deviations of the same sign as the centrifugal force increases.

In the last column of table 5 is shown the moisture equivalents at 1000 g

calculated by the linear formula of nearest fit, for comparison with the values calculated by the quadratic formula. Neither the standard deviation nor the coefficient of variation is so narrow as when a parabolic formula is used, but the difference is not large. It would seem from a consideration of data in tables 4 and 5 that it would be preferable to adopt 1500 *g* obtained by 2990 revolutions per minute as the centrifugal force to be used in determinations

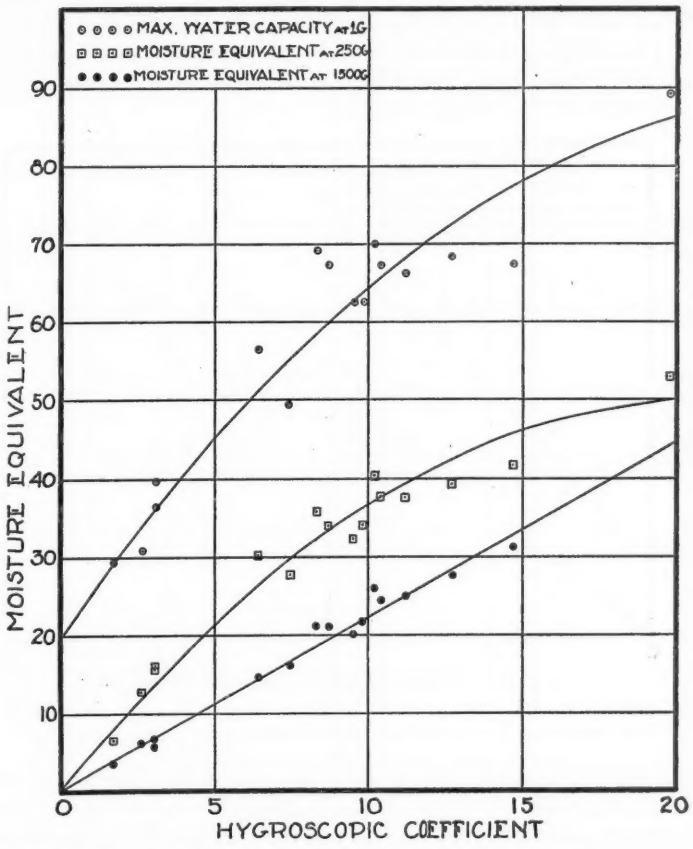


FIG. 6. RELATION OF THE HYGROSCOPIC COEFFICIENT TO THE MOISTURE EQUIVALENT, DETERMINED AT DIFFERENT CENTRIFUGAL FORCES, 1, 250, AND 1500 *g*

of the moisture equivalent. However, since the use of 1000 *g* obtained by a speed of 2440 revolutions per minute has become established and hundreds of moisture equivalents obtained at that force have been published, and since it has been found practical to construct a centrifuge that will stand up

for years at such a speed, it is obviously not desirable to recommend a change for the small increase in accuracy that would be obtained.

Is a 10 millimeter depth of soil most desirable?

An increase of 2 mm. in the depth of soil layer in the cup has been found to lower the moisture equivalent of all soils to the same extent, about 1 per cent. This would diminish the value of the moisture-equivalent-hygroscopic coefficient ratio by a variable fraction, decreasing as the hygroscopic coefficient and moisture equivalent increase. No change in the 10 mm. depth of soil now employed would lead to any nearer constancy in the ratio of moisture equivalent to hygroscopic coefficient.

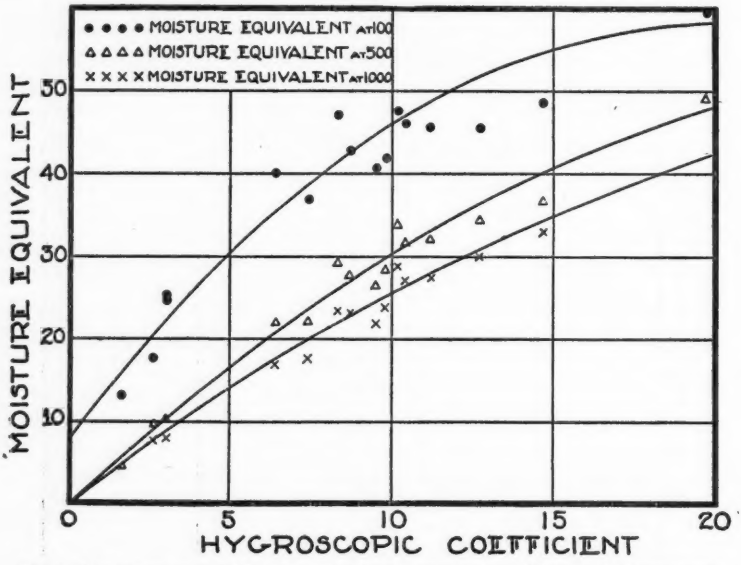


FIG. 7. RELATION OF THE HYGROSCOPIC COEFFICIENT TO THE MOISTURE EQUIVALENT DETERMINED AT DIFFERENT CENTRIFUGAL FORCES, 100, 500, AND 1000 *g*

If the moisture equivalent is valued as an index of the field-carrying capacity, decreasing the depth of soil in the cup to 5 mm. would raise the moisture equivalent of coarse-textured soils 2.5 per cent closer to their field-carrying capacity, but would also raise the moisture equivalent of fine-textured soils a like amount, and in case of very heavy soils their moisture equivalents are already possibly in excess of their field-carrying capacities. Furthermore, it is harder to get concordant duplicate determination for depths much less or greater than 10 mm. The adopted depth of the soil in the cup should be closely adhered to. Inasmuch as Thomas has promised further work on the effect of depth on the moisture equivalent, we have not attempted to carry this phase of the subject further.

Is a 40-minute period for centrifuging most desirable?

Inasmuch as a 20-minute decrease in the period of centrifuging changes the moisture equivalent of all soils by only the insignificant amount of 0.6 per cent, it would seem that a reduction of the period to 20 or 30 minutes would be economical and would speed up laboratory investigation without seriously affecting conclusions, except where strict interpretations of ratios to the other physical constants are involved. For use as an index of field-carrying capacity the moisture equivalent might be determined at 20 minutes for sandy soils and 40 minutes for others. However, such a practice would introduce confusion into the data of various workers and is not to be recommended.

TABLE 5

Deviation of the calculated from the determined moisture equivalents at various multiples of gravity using quadratic formulas

SOIL	M.W.C.	250 *g*	500 *g*	1000 *g*	1500 *g*	1000 *g* BY LINEAR FORMULA
A	−0.2	1.3	1.4	0.9	0.3	0.3
B	3.3	−0.9	−0.4	0.2	−0.1	−0.7
C	−0.4	−1.7	0.4	1.3	0.8	0.3
D	−3.8	−2.3	0.4	1.2	0.2	0.2
E	−5.6	−3.7	−1.3	0.4	−0.2	−0.7
F	5.6	2.0	1.5	2.2	0.6	1.2
G	−10.8	−3.5	−3.3	−1.4	−1.4	−2.3
H	−7.6	−0.3	−0.9	−0.4	−1.5	−1.2
I	0.1	3.6	2.6	2.4	1.3	1.9
J	1.1	2.5	1.4	1.2	0.2	0.8
K	−4.9	−2.6	−3.3	−3.0	−3.1	−3.2
L	−1.4	0.1	−0.7	−0.8	−1.0	−0.9
M	2.0	2.1	0.8	0.4	0.1	0.6
N	4.0	3.6	1.7	0.8	0.8	1.9
O	9.9	4.3	3.0	1.5	1.8	4.0
P	−3.6	...	...	...	...	...
Standard deviation.....	±5.3	±2.7	±1.9	±1.5	±1.2	±1.8
Coefficient of variation....	±9.0	±9.1	±8.0	±7.8	±6.7	±9.3

SUMMARY

The effect of speed, period of centrifuging, and depth of soil layer in the cup on the moisture equivalent, has been studied for 16 widely different soils in an attempt to arrive at either a less empyrical definition of the moisture equivalent or a better appreciation of the necessity of strict adherence to the present adopted procedure.

The relation of the moisture equivalent to the centrifugal force employed is not linear as previously suggested, but is represented by the equation $M = \frac{K}{G^n}$ where M is the moisture equivalent obtained at the centrifugal

force G in terms of gravity, and n and K are characteristic constants for each soil.

The moisture equivalent is decreased about 1 per cent for each soil when the depth of the layer in the moisture-equivalent cup is increased from 10 mm. to 12 mm. The moisture equivalent decreases 0.6 per cent for each soil for each 20-minute increase in the period of centrifuging after the first 20 minutes.

The ratio of the moisture equivalent to the hygroscopic coefficient is practically linear only at 1000 g and upwards. The equation of the relation of moisture equivalent (and maximum water capacity) to the hygroscopic coefficient is a simple parabola of form $a + bx + cx^2 =$ moisture equivalent where x is the hygroscopic coefficient. For very low values of g, (1 g to 100 g) a, b, and c are constants of considerable magnitude. As the force of centrifuging is increased, first a and later c reduces to zero, and the equation becomes linear.

The relation of moisture equivalent to hygroscopic coefficient is not a natural constant, but an experimental one only, in which a considerable element of probable variation exists. The probable variation is the same at all centrifugal forces when the relation of hygroscopic coefficient to moisture equivalent is expressed as a quadratic formula, but when expressed as a linear formula, the probable variation is a minimum between 1000 and 1500 g.

The moisture equivalent is best defined as Briggs and McLane have defined it, that is, centrifugal force 1000 g; depth of soil, 10 mm.; period, 40 minutes. It is indeed fortunate that so near the desirable requirements were decided upon.

A technique for the determination slightly different from that proposed by Briggs and McLane is described.

REFERENCES

(1) Alway, F. J., and McDole, G. R. 1917 Relation of the water retaining capacity of a soil to its hygroscopic coefficient. *In* Jour. Agr. Res., v. 9, no. 2, p. 27–71.

(2) Alway, F. J., and Russel, J. C. 1916 Use of the moisture equivalent for the indirect determination of the hygroscopic coefficient. *In* Jour. Agr. Res., v. 6, no. 22, p. 833–846.

(3) Briggs, L. J., and McLane, J. W. 1907 The moisture equivalent of soils. U. S. Dept. Agr. Bur. Soils Bul. 45.

(4) Briggs, L. J., and McLane, J. W. 1910 Moisture equivalent determinations and their application. *In* Proc. Amer. Soc. Agron., v. 2, p. 138–147.

(5) Briggs, L. J., and Shantz, H. L. 1912 The wilting coefficient for different plants and its indirect determination. U. S. Dept. Agr. Bur. Plant Indus. Bul. 230.

(6) Israelsen, O. W. 1918 Studies on capacities of soils for irrigation water, and on a new method of determining volume weight. *In* Jour. Agr. Res., v. 13, no. 1, p. 1–36.

(7) Middleton, H. E. 1920 The moisture equivalent in relation to the mechanical analysis of soils. *In* Soil Sci., v. 9, no. 2, p. 159–167.

(8) Russel, J. C. 1918 Relation of certain physical and chemical constants of soils to soil type. Unpublished thesis, Minnesota University.

(9) Smith, Alfred 1917 Relation of the mechanical analysis to the moisture equivalent of soils. *In* Soil Sci., v. 4, no. 6, p. 471–476.

(10) Thomas, M. D. 1921 Aqueous vapor pressure of soils. *In* Soil Sci., v. 11, no. 6, p. 409–434.

THE EFFECT OF THE DIFFERENT DEGREES OF FINENESS OF LIMESTONE UPON DECOMPOSITION OF ORGANIC MATTER IN THE SOIL[1]

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It is a universal practice to apply calcium in some form to lands devoted to crop production. Many factors, such as cost of application, type of soil, ease of handling, quickness of action, and personal prejudice have entered into the choice of the form of carrier to be used. Many experimental data have been brought forth to show that calcium oxide (burned) or calcium hydrate (slaked) forms of lime are more valuable than calcium carbonate (ground limestone, ground oyster shell, and marl) forms of lime for agricultural purposes. Recent reports of several investigators have aroused doubt as to the correctness of such conclusions and some experiments have shown properly ground carbonate forms under certain conditions to be equivalent or superior to the other forms.

Since finer grinding of limestone materials increases the cost of grinding, the question has naturally arisen as to what degree of fineness is satisfactory for agricultural purposes. Investigators have attacked the problem from many different viewpoints and under widely different conditions. The resulting recommendations have been at considerable variance as to how fine the limestone should be ground. These results will be cited later in this paper.

As the practice of green manuring is becoming more prevalent and since the use of lime is often advised in connection with green manures, it seemed desirable to compare the different degrees of fineness of ground limestone with the burned and slaked forms as to their action when applied with a green manure. The problem was taken up from the following standpoints:

Effect of the different degrees of fineness of limestone

1. Upon rate of decomposition
2. Upon soil organisms
3. Upon availability of soil nutrients

EXPERIMENTAL WORK

A number of 6000-gm. composite samples of Sassafras silt loam which had received no fertilizer, manure, or lime applications for 15 years, and which

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had a lime requirement (as determined by the sodium acetate method) of 1000 pounds calcium oxide per acre were ground and samples taken for chemical analysis and for content of soil organisms.

To the proper samples were then added 100 gm. of green manure (crimson clover) and an amount of the different grades of limestone equivalent to 1500 pounds calcium oxide per acre. Calcium oxide was also added to the series of samples in an effort to compare the different degrees of fineness with a readily soluble form of lime. The treatments were made in duplicate.

After the proper amounts of lime materials and green manure had been thoroughly incorporated in the soil the mixture was made up as nearly as possible to optimum moisture content and placed in the apparatus shown in figure 1. This apparatus was set up as follows:

The treated soil was placed in a lysimeter of suitable size and the lysimeter set in a porous pot to allow circulation of air through the bottom of the lysimeter. The pot containing the lysimeter was then set in a shallow pan and covered with a large bell jar having an opening at the top. The bottom of the bell jar was sealed to the pan with a mixture consisting of 2 parts of paraffin and 5 parts of litholine. This mixture was melted and poured into the pan around the base of the bell jar in sufficient quantity effectually to seal the joint. After the mixture had hardened, an additional layer of litholine was poured upon it. This made an airtight seal. The top of the bell jar was then closed with a tightly fitting 2-hole rubber stopper containing 2 glass tubes. One of these, just extending down through the stopper, was connected to a control stopcock upon an air-inlet pipe. This pipe received a supply of carbon dioxide-free air through a sodium hydroxide trap. The other glass tube in the top of the bell jar extended more deeply into the bell jar for the purpose of extracting carbon dioxide given off and causing a circulation of air. The outlet tube was connected with a sodium hydroxide trap containing a known amount of standard solution. This trap was then connected through a control stopcock to a water suction pump. In this manner all quantities of carbon dioxide given off from the different soils in the lysimeters were collected in their respective sodium hydroxide traps. These traps were replaced at such times as were necessary and a determination made of the carbon dioxide collected.

The apparatus was run 5 months. It was then taken down and the soils sampled for bacterial content and for chemical analysis. The results obtained, together with results of similar experiments carried on by other investigators, will be given in the remainder of this paper.

EFFECT UPON ORGANIC MATTER AND SOIL HUMUS

White and Holben (27) reported that there was no significant difference in the action of burned lime and limestone on soil organic matter at the end of 40 years of continuous treatment and that lime had conserved rather than depleted nitrogen and organic matter.

Mooers and MacIntire (25) reported that at a 2-ton rate the oxide, hydrate and carbonate produced losses of nitrogen quite similar. However, at an 8-ton rate the oxide and hydrate gave rise to large losses. Also the 8-ton rate of ground limestone produced much larger yields of cowpeas than did any other form. This he attributes partly to high flocculating action. The

evidence was conclusive that both the oxide and hydrate at heavy rates of application result in a waste of nitrogen.

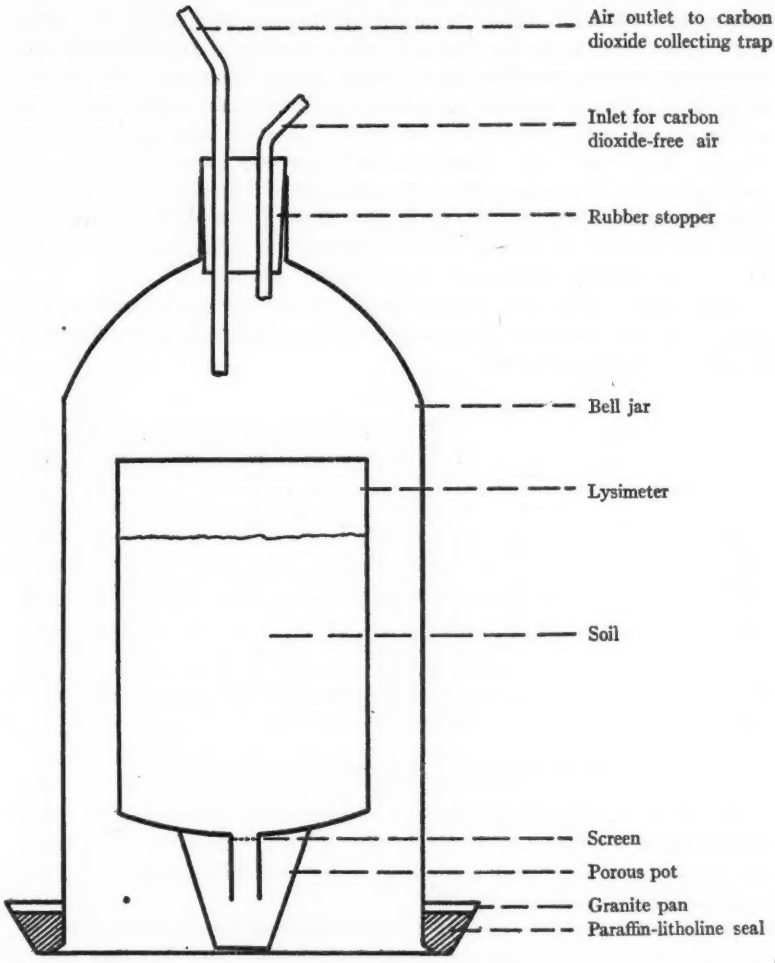

FIG. 1. DIAGRAM SHOWING ARRANGEMENT OF APPARATUS FOR COLLECTION OF CARBON DIOXIDE GIVEN OFF FROM THE SOIL

Experimental results

The carbon dioxide given off by the different treatments was taken as an index of the changes occurring in the organic-matter content of the soil. The average grams of carbon dioxide collected from the duplicate treatments

during the different periods are recorded in table 1 to show the rate at which decomposition occurred.

Table 1 shows that at the end of the first 10 days the rank in rate of CO_2-release was: 100-mesh highest, followed by 20-mesh, 60-mesh, no limestone and calcium oxide in the order named. At the end of 20 days all totals were quite close together, no difference worthy of note being shown. At the end of 30 days, 100-mesh and calcium oxide had given off the larger amounts of carbon dioxide, and 20-mesh, 60-mesh and no limestone were grouped closely together at a lower total. After this time there was a very gradual rise in total from all of the treatments until at the end of 5 months there was very little appreciable difference shown in the 60-mesh, 100-mesh, and calcium oxide treatments. In amount of CO_2, 20-mesh was considerably lower, and the no-lime treatment was lowest in total amount given off.

These results show that calcium oxide, 100-mesh ground limestone and 60-mesh ground limestone are equally effective in promoting decomposition of organic matter in the soil.

TABLE 1

Total CO_2 collected

	7 DAYS	17 DAYS	27 DAYS	43 DAYS	60 DAYS	90 DAYS	120 DAYS	150 DAYS
	gm.	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*	*gm.*
Check	0.95	12.65	17.31	19.69	21.89	24.84	28.01	30.65
CaO	0.59	12.25	18.59	21.67	24.57	28.18	31.17	33.68
100-mesh	2.62	12.14	18.88	22.09	25.06	28.18	31.26	33.90
60-mesh	1.41	12.23	17.38	20.20	22.95	26.78	30.30	33.44
20-mesh	1.73	11.67	17.17	20.12	22.91	26.12	29.15	31.72

It should be noted that no attempt has been made to include in the table any correction for CO_2 added in the carbonate. It is also of importance to note in connection with the CaO that CO_2 would be absorbed at the beginning of the experiment.

EFFECT UPON THE AVAILABILITY OF NUTRIENTS

Kellner, et al. (17) carried on extensive work as to the effect of lime upon phosphorus. No change in the availability of the soil phosphorus was shown, the results being due mainly to a change in the availability of the phosphorus carried in the organic matter.

Morse and Curry (23) found that calcium hydrate solutions would liberate potash from orthoclase, but concluded from field studies that lime was of little benefit in releasing potash.

Gaither (11) in a study of the effect of lime upon the availability of soil constituents concluded that little if any potash was liberated by the action of lime on the soils.

Mooers (24) reported that lime increased the efficiency of acid phosphate but depressed that of ground rock phosphate.

Ellett and Hill (7) found that the addition of lime exerted a depressing

effect upon the insoluble calcium phosphates. This indicates that some injury might be done by over-liming.

Fraps (8) from pot studies found no appreciable liberation of potash by calcium carbonate either as measured by 0.2*N* solvents or by the amounts taken up by the crop.

Briggs and Breazeale (3) found that calcium hydrate had no effect on liberating potash from orthoclase-bearing rock.

Experimental results

A 1-per cent solution of citric acid was used as the solvent. Increases in amounts of available potassium and phosphorus are shown in the following table.

TREATMENT	INCREASE	
	Potassium	Phosphorus
	per cent	*per cent*
20-mesh	0.0058	0.00295
60-mesh	0.0096	0.00682
100-mesh	0.0094	0.01286
CaO	0.0122	0.00434
Green manure alone	0.0065	0.00062

That these increases are not greater than the amounts added in the green manure may or may not have been due to liberation from the organic matter.

EFFECT UPON SOIL ORGANISMS

Withers and Fraps (28) found that calcium carbonate added to a soil greatly accelerated nitrification.

Chester (5) showed that lime increased the number of bacteria in the soil, the increase being proportional to the lime applied up to 4000 pounds per acre.

Hartwell and Kellogg (12) proved conclusively that lime increased the decay taking place in the soil.

Lipman and Brown (18) showed that calcium carbonate markedly stimulated nitrification, and their later results showed that both ammonification and nitrification were increased by it.

Lipman, Brown and Owen (19) found that large applications had a detrimental effect upon ammonification.

Lyon and Bizzell (20) found that lime favored nitrification.

Kellermann and Robinson (16) indicated that high percentages of carbonate inhibited nitrification. It was not harmed up to 2 per cent calcium carbonate. Calcium carbonate also showed a protective influence against the toxic properties of magnesium carbonate.

Brown (4) working upon a Wisconsin drift soil found that ground-lime applications up to 3 tons per acre increased the number of bacteria in the soil and also the ammonifying, nitrifying and nitrogen-fixing powers of the soil. The increase was in every case nearly proportional to the limestone applied.

Hutchison and MacLennan (15) showed that small quantities of lime increased very markedly the total bacteria content of the soil but large applications caused a fairly rapid decrease. He found that carbonate of lime increased the rate of ammonification in organic nitrogenous material.

Experimental results

The soils from the different treatments were sampled and cultured by the usual plating methods.

Dilutions of 1:10,000 and 1:100,000 were used. The ammonifiers were cultured on nutrient agar media. The nitrifiers were cultured on a special media which is a modification of Manns (22) manure extract. To make the

TABLE 2

*Effect upon soil organisms**

	AZOTOFIERS		NITRIFIERS	AMMONIFIERS	ACTINOMYCES	FUSARIA	OTHER MOLDS
	B. Rad.	Azotobacter					
Soil alone	5	4	10	6	15		3
Green manure	11	13	10	35	32	1	7
CaO	20	20	20	34	49	2	9
100-mesh	8	9	16	20	25		2
60-mesh	12	10	24	35	45		2
100-mesh	16	18	25	46	50		4

* Multiply all figures by 100,000.

media, from a mixture of 2000 cc. water, 500 gm. well-rotted manure, 1 gm ammonium tartrate and 1 gm. ammonium citrate, 1000 cc. is extracted and added to 2 gm. wood ashes and 12 gm. agar. The azotobacter, actinomyces, and fusaria were cultured on Ashby's (1) mannite solution.

The results given in table 2 show that calcium oxide and 100-mesh limestone were practically equal in stimulating effects upon bacterial content. The 60-mesh limestone showed little difference in effect from that produced by the green manure alone. All treatments greatly surpassed the untreated soil in bacterial content.

SUMMARY

1. In promoting decomposition of organic matter in the soil 60-mesh and 100-mesh limestone materials are fully as effective as calcium oxide.

2. Calcium oxide and 100-mesh limestone produce similar results and also the most favorable effects upon activity of organisms in the soil.

3. No appreciable difference in effect upon availability of soil phosphorus or soil potassium is shown by addition of the different lime materials.

4. The results recorded in this paper are in accord with those of other investigations and lead to a similar conclusion.

REFERENCES

(1) ASHBY, S. F. 1914 Some observations on the assimilation of atmospheric nitrogen by a free living soil organism.—Azotobacter chroococcum of Beijerinck. *In* Jour. Agr. Sci., v. 2, p. 38.

(2) BARKER, J. F., AND COLLISON, R. C. 1915 Ground limestone for sour soils. N. Y. (Geneva) Agr. Exp. Sta. Bul. 400.

(3) BRIGGS, L. J., AND BREAZEALE, J. F. 1917 Availability of potash in certain orthoclase-bearing soils as affected by lime or gypsum. *In* Jour. Agr. Res., v. 8, no. 1, p. 21.

(4) BROWN, P. E. 1911 Some bacteriological effects of liming. *In* Iowa Agr. Exp. Sta. Res. Bul. 2, p. 49–107.

(5) CHESTER, F. D. 1901 Studies in soil bacteriology. *In* Del. Agr. Exp. Sta. 13th Ann. Rpt. p. 50–73.

(6) CHESTER, F. D. 1904 The bacteriological analysis of soils. *In* Del. Agr. Exp. Sta. Bul. 65, p. 51–76.

(7) ELLETT, W. B., AND HILL, H. H. 1911 Contribution to the study of phosphoric acid in soils and fertilizers. *In* Va. Agr. Exp. Sta. Rpt. 1909–1910, p. 44–65.

(8) FRAPS, G. S. 1916 The effect of additions on the availability of soil potash and the preparation of sugar humus. Tex. Agr. Exp. Sta. Bul. 190.

(9) FRAPS, G. S. 1917 Effect of lime and carbonate of lime on acid phosphate. Tex. Agr. Exp. Sta. Bul. 223.

(10) FREAR, W. 1915 Sour soils and liming. *In* Pa. Dept. Agr. Bul. 261, p. 149.

(11) GAITHER, E. W. 1910 The effect of lime upon the solubility of soil constituents. *In* Jour. Indus. Engin. Chem., v. 2, no. 7, p. 315.

(12) HARTWELL, B. L., AND KELLOGG, J. W. 1905 The effect of liming upon certain constituents of the soil. *In* R. I. Agr. Exp. Sta. 18th Ann. Rpt., p. 242–252.

(13) HASKINS, H. D. 1911 The distribution, composition and cost of lime. Mass. Agr. Exp. Sta. Bul. 137.

(14) HOPKINS, C. G. 1907 Ground limestone for acid soils. Ill. Agr. Exp. Sta. Cir. 110.

(15) HUTCHINSON, H. B., AND MACLENNAN, K. 1914 The relative effect of lime as oxide and carbonate on certain soils. *In* Jour. Agr. Sci., v. 6, no. 3, p. 302.

(16) KELLERMAN, K. F., AND ROBINSON, T. R. 1910 Lime and legume inoculation. *In* Science, v. 32, p. 159–160.

(17) KELLNER, O., ET AL. 1891 Researches on the action of lime as a manure with special regards to paddy fields. *In* Col. Her. Tokyo Bul. 9, p. 1–25.

(18) LIPMAN, J. G., AND BROWN, P. E. 1907 Ammonification in culture solution as affected by soil treatment. *In* N. J. Agr. Exp. Sta. 28th Ann. Rpt., 141–204.

(19) LIPMAN, J. G., BROWN, P. E., AND OWEN, I. L. 1909 Experiments on ammonia and nitrate formations in soils. *In* N. J. Agr. Exp. Sta. 30th Ann. Rpt., p. 117–180.

(20) LYON, T. L., AND BIZZELL, J. A. 1909 Some conditions favoring nitrification of soils. *In* Science, n. s., v. 30, p. 773–774.

(21) MACINTIRE, W. H. 1915 Sour soils and liming. *In* Pa. Dept. Agr. Bul. 261, p. 160.

(22) MANNS, T. F., AND GOHEEN, J. M. 1916 A preliminary report on muck humus as a fertilizer and carrier of beneficial soil bacteria. Del. Agr. Exp. Sta. Bul. 115.

(23) MORSE, F. W., AND CURRY, B. E. 1909 Availability of soil potash in clay and clay loam soils. *In* N. H. Agr. Exp. Sta. Bul. 142, p. 49.

(24) MOOERS, C. A. 1912 Fertility experiments in a rotation of cowpeas and wheat. Tenn. Agr. Exp. Sta. Bul. 96.

(25) MOOERS, C. A., AND MACINTIRE, W. H. 1921 Comparative effects of various forms of lime on the nitrogen content of the soil. *In* Jour. Amer. Soc. Agron., v. 13, no. 5. p. 185–205.

(26) PATTEN, A. J., AND JEFFERY, J. A. 1911 Lime for agricultural purposes. Mich. Agr. Exp. Sta. Cir. 11.

(27) WHITE, J. W., AND HOLBEN, F. J. 1924 Effect of lime on decomposition of soil organic matter. *In* Soil Sci., v. 18, no. 3, p. 201–214.

(28) WITHERS, W. A. AND FRAPS, G. S. 1900 The relative value of some nitrogenous fertilizers. *In* N. C. Agr. Exp. Sta. Bul. 176, p. 15–22.

AVAILABILITY OF NUTRIENTS IN SUBSOILS

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The correctness of the statement by Russell (8) "It is well known that only the top 6 or 8 inches of the soil is suited to plant life, and that the lower part or subsoil, plays only an indirect part in plant nutrition," is frequently questioned. Alway, McDole and Rost (1) ascribe some of this difference of opinion to a failure to distinguish between inoculated legumes and non-legumes. Their experiments and observations show that certain subsoils of eastern Nebraska are very unproductive in so far as non-legumes are concerned, while inoculated legumes thrive on them almost as luxuriantly as on the surface soils.

From his observations in California, Lipman (4) disagrees with the long-accepted opinion of Hilgard that arid subsoils are not "raw" in so far as non-legumes are concerned. He further points to a lack of evidence to prove that humid subsoils are "raw" to inoculated legumes.

Harmer (3) found that alfalfa grew as well on two Minnesota subsoils as on the corresponding surface soils but that five other subsoils were far less productive for this plant than the accompanying surface horizons. The unproductiveness of two of these subsoils was found by McMiller (7) to be overcome largely by additions of soluble phosphates and potassium salts.

Weaver, Jean and Christ (9) and Christ and Weaver (2) have shown quite conclusively that corn, oats, barley, potatoes and two grasses native to the western plains are capable of absorbing soluble nitrates and phosphates from the lower soil horizons, but they have left unanswered the question as to whether under natural conditions these crops do remove such nutrients.

By studying the rate of solubility of subsoils from sections of the United States having widely different climatic characteristics, McCool and Millar (5) arrived at the conclusion that very small amounts of mineral nutrients pass into solution from the lower soil horizons unless these horizons contain alkali salts.

In view of the great differences which have been shown to exist in both the chemical and physical properties of the various horizons of several soil profiles [McCool, Veatch and Spurway (6) and Wheeting (10)], it would appear that much of the disagreement regarding the "rawness" of the lower horizons may be due to a lack of uniformity in the samples of so-called "subsoil" utilized by different investigators.

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As suggested by previous workers, the individuality of the root systems of various plants may also lead to marked differences in the amount of nutrients removed from the lower horizons of the soil profile.

The present investigation was designed to determine (a) whether the corn plant draws an appreciable quantity of nutrients from the portion of the soil below the dark-colored surface layer in two prominent soil types of Michigan; (b) whether there is any appreciable difference in the amount of nutrients supplied to corn by the lower horizons of the Leslie sandy loam.

EXPERIMENTAL

In preliminary experiments an attempt was made to ascertain whether corn roots draw significant quantities of nutriment from the horizons of Coloma loamy sand and Leslie sandy loam below the dark-colored, humus-bearing layer. Unglazed drain tiles, 3 by 12 inches, were set so that the tops were very slightly above the surface of the ground. By planting the corn in these containers it was possible to keep the roots out of the surface soil while allowing

TABLE 1

Height of corn grown in 3-inch tiles filled with Coloma loamy sand

TREATMENT	HEIGHT OF PLANTS
	cm.
Tile filled with surface soil	81.7
Tile filled with soil from horizons A_2 and B	37.8
Tile filled with soil from horizons A_2 and B (fertilizer at the sides)	43.9
Tile filled with soil from horizons A_2 and B (fertilizer below)	55.3

unrestricted ramification in the lower horizons. It was sought to make the corn draw all of its nutrients from the lower horizons, in some cases by filling the tiles with this material, while in others the filling was done with surface soil thus allowing access to a limited amount of surface material.

A small quantity of complete fertilizer was placed 4 or 5 inches below and 6 or 7 inches to the side of the lower end of the tile in some instances, in others 3 or 4 inches directly below the tile and in other cases no fertilizer was used. The influence of these treatments as indicated by the height attained by the corn on Coloma loamy sand is shown in table 1. The data represent the average of plants from 10 containers.

The comparatively small growth of the corn in the tile filled with soil from horizons A_2 and B indicates that little nutriment is drawn from this portion of the Coloma profile. Weight is added to this conclusion by the greater height attained when fertilizer was placed below the tiles where the roots usually came in contact with it. The relative root development in the two cases is shown in figures 1 and 2, plate 1.

In only a few cases did the roots find the fertilizer placed below and to the

side of the tile, but when they did, a mass of roots developed in that location as is shown in figure 3, plate 1.

The influence of the available nutrients contained in the limited supply of surface soil with which some of the tiles were filled is shown by the height of the plants and also by the large root development. This is well brought out by a comparison of figure 1, plate 2 and figure 1, plate 1.

The results of the experiments on Leslie sandy loam were very similar to those on the Coloma loamy sand during the early part of the season, in that those plants growing in the tiles filled with surface soil were much larger than those in tiles containing soil from the yellowish gray or A_2 horizon which occurs immediately below the surface soil. As the season advanced, however, these differences disappeared. The results are shown in table 2.

The greater average height of the plants grown in horizon A_2 was due to the unusual growth in two tiles, of the plants which succeeded in getting a few of their roots over the tops of the tiles and into the surface soil where they developed without restriction. The great mass of roots which developed from the few main ones reaching over the tile is shown in figure 1, plate 3.

TABLE 2

Height of corn grown in 3-inch tiles filled with Leslie sandy loam

TREATMENT	HEIGHT OF CORN
	cm.
Tile filled with surface soil	59.7
Tile filled with surface soil; fertilized at the side	60.8
Tile filled with surface soil; fertilized below	55.7
Tile filled with soil from horizon A_2	67.0

With these two cultures omitted, the average height of the plants growing in sub-soil was 60.6 cm.

No stimulation of growth was noted as a result of fertilizer placed either below or to the side of the bottom of the tile. In this respect the results are somewhat different from those obtained on the sandy soil.

The behavior of the plants in this experiment, especially those on the Leslie soil, led to the belief that the small size of the tiles was more or less a determining factor in the results. Consequently it was decided in the next experiment to use larger containers, of which two types were chosen. Wooden boxes 1 foot square and 1 foot deep without bottoms were set so that the top was slightly above the surface of the Coloma soil. Glazed tiles 10 by 24 inches were similarly placed in the Leslie soil.

The soil horizon with which the boxes were filled, together with the yield of air-dry plant tissue (stalks + grain) produced, is shown in table 3.

It was not the plan of the experiment to add soluble nitrogen to boxes 1 and 4, but during the early part of the season, July 2, since the corn in these boxes as well as that in number 2 appeared to be dying it was deemed ad-

visable to furnish it with a small amount. This was done by adding 500 cc. of a solution containing 0.08 gm. NH_4NO_3 per liter. The remainder of the nitrogen supplied to boxes 2 and 4 was added in solution on July 17. The heights of the plants in boxes 1, 2 and 4 were practically the same July 11, averaging 7 inches. They were yellow and extremely unthrifty in appearance. The plants in number 3 were 32 inches high, dark green in color and exceedingly thrifty.

A consideration of the final data leads one to the conclusion that corn draws very little nutriment from horizon C of the Coloma profile and that the lack of growth on this material is not due to a lack of available nitrogen. The vigorous growth of the plants in surface soil indicates the presence of a large supply of available nutrients. The ultimate development of the plants having access to surface soil placed below the first foot after a very precarious existence, presumably before the roots penetrated to this depth, also testifies to the availability of nutrients in this horizon. Figures 2 *A* and *B*, plate 2, show the relative growth of the plants in boxes 1 and 3 on July 10.

TABLE 3

Yield of air-dry corn produced in boxes of Coloma loamy sand

BOX NUMBER	TREATMENT	YIELD OF AIR-DRY CORN
1	Soil from horizon C—0.04 gm. NH_4NO_3	40.70
2	Soil from horizon C—0.54 gm. NH_4NO_3	54.11
3	Surface soil	142.87
4	8 inches of surface soil below the box which was then filled with soil from horizon C—0.54 gm. NH_4NO_3	112.42

Some of the tiles in the Leslie sandy loam were filled entirely with surface soil, others were filled with the yellowish gray horizon lying immediately below the surface layer, while in other cases the next or brown horizon of maximum clay was used. Some containers were filled with horizons A_2 and B to within 8 inches of the top, the filling being completed with surface soil; while for contrast, 8 inches of surface soil was placed below the tile in several cases, horizons A_2 and B being used for the filling. To make sure that the plants growing in subsoil did not lack for available nitrogen, during the season two applications of NH_4NO_3 solution were made to half of the containers filled with this material.

The weights of air-dry corn produced are shown in table 4. The data are the average weight of material from three to six containers.

The preceding data lead one to conclude that the amount of surface soil with which the roots came in contact was the first limiting factor in the growth of the corn. Beyond a certain point, however, the actual restriction of the root system appeared to limit the development of the plants.

The quite satisfactory growth of the plants whose roots had contact with surface soil at a depth of 2 feet only, strengthens the opinion that the surface

soil is the primary source of nutrients for the corn plant. These results, as well as those from the boxes filled with sand from the lower horizons of Coloma but containing surface soil below, not only substantiate Christs' findings that the lower portions of the root systems are capable of absorbing available nutrients, but expand them, since in these experiments the nutrients were taken not from added salts but from natural soil.

The amount of growth attained when the plants had access to the lower horizons indicates only a very meagre supply of available nutrients in this material. The amounts obtained by the corn from the two horizons tested were not appreciably different if growth be taken as a criterion. The increased growth resulting from the addition of available nitrogen was well within the limits of experimental error. The conclusion would seem justified, therefore, that a lack of available nitrogen was not the determining factor in the growth of the corn.

TABLE 4

Yields of air-dry corn produced on different horizons of Leslie sandy loam

SOIL HORIZON AND TREATMENT	AIR-DRY CORN
	gm.
Surface soil	177.5
Horizon A_2 and B with 8 inches of surface soil on top	143.3
Horizon A_2 and B with 8 inches of surface soil below the tile	111.0
Horizon A_2	26.8
Horizon A_2—0.54 gm. NH_4NO_3	31.5
Horizon B	20.6
Horizon B—0.54 gm. NH_4NO_3	22.4

CONCLUSION

Corn was found to make very little growth on the portions of the profiles of Coloma loamy sand and Leslie sandy loam below the surface or humus-bearing horizon. Further the third or often so-called "concentration" horizon of the Leslie supported no greater growth than did the second or leached horizon. The addition of available nitrogen had an inappreciable effect on the amount of growth.

If the amount of growth be taken as a measure of the availability of nutrients in the horizons studied, it must be concluded that the corn plant draws very sparingly on the soil horizons below the surface.

REFERENCES

(1) ALWAY, F. J., MCDOLE, G. R., AND POST, C. O. 1917 The Loess soils of the Nebraska portion of the transition region: VI. The relative "rawness" of the subsoils. *In* Soil Sci., v. 3, no. 1, p. 9–35.

(2) CHRIST, J. W., AND WEAVER, J. E. 1924 Absorption of nutrients from subsoil in relation to crop yield. *In* Bot. Gaz., v. 77, no. 2, p. 121–148.

(3) HARMER, P. M. 1918 The relative "rawness" of some humid subsoils. *In* Soil Sci., v. 5, no. 5, p. 393–401.
(4) LIPMAN, C. B. 1917 The "rawness" of subsoils. *In* Science, v. 46, p. 288–290.
(5) MCCOOL, M. M., AND MILLAR, C. E. 1920 The formation of soluble substances in soils taken from widely separated regions. *In* Soil Sci., v. 10, no. 3, p. 219–235.
(6) MCCOOL, M. M., VEATCH, J. O., AND SPURWAY, C. H. 1923 Soil profile studies in Michigan. *In* Soil Sci., v. 16, no. 2, p. 95–106.
(7) MCMILLER, P. R. 1919 Some notes on the cause of the unproductivity of "raw" subsoils in humid regions. *In* Soil Sci., v. 7, no. 3, p. 233–236.
(8) RUSSELL, E. J. 1917 Soil Conditions and Plant Growth, ed. 3, p. 56. Longmans, Green & Co., London.
(9) WEAVER, J. E., JEAN, F. C., AND CHRIST, J. W. 1922 Development and activities of roots of crop plants. Carnegie Inst. Washington Pub. 316.
(10) WHEETING, L. C. 1924 Some physical and chemical properties of several soil profiles. Mich. Agr. Exp. Sta. Tech. Bul. 62.

PLATE 1

FIG. 1. Root development of corn growing in a 3-inch tile filled with horizons A_2 and B from Coloma loamy sand.

FIG. 2. Root development of corn grown in a 3-inch tile filled with horizons A_2 and B from Coloma loamy sand. Small quantities of complete fertilizer were placed approximately 3 inches below the end of the tile.

FIG. 3. Showing large cluster of rootlets which developed when a root came in contact with a supply of fertilizer. Corn in tile filled with horizons A_2 and B from Coloma loamy sand.

FIG. 1

FIG. 2

FIG. 3

PLATE 2

FIG. 1. Root development of corn growing in a 3-inch tile filled with surface soil from Coloma loamy sand. Compare with figures 1 and 2, plate 1.

FIG. 2*A*. Corn growing in a frame 12 by 12 inches filled with horizon C from Coloma loamy sand.

FIG. 2*B*. Corn in similar frame filled with surface soil from Coloma loamy sand. July 10, 1924.

FIG. 1

FIG. 2a

FIG. 2b

PLATE 3

FIG. 1. Showing the large root development in the surrounding surface soil from a few main roots extending over the edge of a 3-inch tile filled with horizon A_2 from Leslie sandy loam.

FIG. 1

CERTAIN RELATIONSHIPS BETWEEN ADDED SALTS AND THE MOISTURE OF SOILS

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The relationships set up between the moisture of the soil and a salt added to it are of interest because of the mutual effect of the water on the solution and movement of the salt, and the effect of the salt on the movement of moisture. Certain aspects of these reationships have been investigated and form the subject matter of this paper. Other phases of the work have already been published (2).

METHODS OF PROCEDURE

Glass cylinders, 8 inches long and $1\frac{7}{8}$ inches in diameter were employed in studying the effects of varying moisture conditions upon the movements of salts and moisture in soils. The cylinders were filled about one-half full of soil which had been made up to the desired moisture content; then 2 gm. of crystalline potassium chloride and sodium carbonate respectively were put in and uniformly spread over the surface. The tubes were then filled with the soil and finally sealed at both ends with melted paraffin. The filled cylinders thus had about 4 inches of soil on each side of the 2-gm. deposit of salt, the soil weighing 500 gm. in the case of sand and 450 gm. when silt loam was used. These cylinders were set away at a nearly constant temperature of 18°C. for suitable lengths of time which, in this series, were for periods of 10 and 20 days. At the close of each period they were opened and 1-inch layers of the soil removed, placed in weighed aluminum cans and dried at 103°C., for about 48 hours. They were then cooled and weighed and the moisture calculated as a percentage for each section, the percentages being based on oven-dry soil.

The salt movement itself was detected by means of the freezing point apparatus described by Bouyoucos (1). Twenty grams of air-dry soil was moistened with 10 cc. of distilled water and after standing for about 1 hour was frozen in the prescribed manner.

EXPERIMENTAL RESULTS

I. The influence of moisture-content on the movement of salts and the movement of moisture

The first series of moisture experiments were run with air-dry medium sand and air-dry silt loam over 10- and 20-day periods. The results are shown in table 1.

It will be noticed that no movement of salt or moisture occurred. It appears, then, that soils with only the unfree water present are inactive with respect to salt and moisture movements. This is probably due to the unavailability of this form of soil moisture as well as to the lack of its continuous contact in the column.

A second series of experiments were carried on with medium sand at a moisture content of 0.5 per cent, and with silt loam at 2.0 per cent. Some difficulty was encountered in obtaining a homogeneous mixture with such small quanti-

TABLE 1

Movements of salts and moisture in air-dry soils

DISTANCE FROM SALT LAYER	SILT LOAM				SAND			
	After 10 days		After 20 days		After 10 days		After 20 days	
	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content
inches	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*
2 grams KCl added								
4	0.007	1.56	0.006	1.36	0.002	0.25	0.002	0.21
3	0.004	1.77	0.006	1.43	0.004	0.26	0.002	0.24
2	0.005	1.62	0.005	1.30	0.004	0.26	0.003	0.24
1	0.007	1.68	0.006	1.44	0.004	0.28	0.005	0.18
1	0.008	1.58	0.008	1.54	0.005	0.26	0.005	0.24
2	0.006	1.57	0.007	1.41	0.002	0.24	0.005	0.22
3	0.006	1.44	0.007	1.54	0.002	0.26	0.002	0.26
4	0.005	1.61	0.006	1.59	0.002	0.27	0.002	0.27
2 grams Na_2CO_3 added								
4	0.006	1.47	0.006	1.47	0.002	0.27	0.003	0.27
3	0.006	1.49	0.004	1.64	0.002	0.29	0.003	0.25
2	0.004	1.43	0.005	1.55	0.003	0.31	0.003	0.27
1	0.006	1.54	0.005	1.64	0.004	0.28	0.005	0.25
1	0.005	1.62	0.003	1.49	0.005	0.27	0.004	0.29
2	0.004	1.51	0.003	1.52	0.005	0.27	0.004	0.26
3	0.004	1.67	0.004	1.49	0.002	0.26	0.004	0.23
4	0.003	1.70	0.004	1.52	0.002	0.26	0.004	0.22

ties of water. The results for periods of 10 and 20 days are shown in table 2. In contrast with the results of table 1 these data show both salt and moisture movements. The appearance of a dark ring around the zone where the salt was placed, was plainly due to the increase in the moisture content which collected there at the expense of the outward layers. The salts moved only as far as this dark zone proceeded. This zone was most marked in the case of potassium chloride and sand, but was readily observable with silt loam. Under these conditions of moisture the sodium carbonate was less active in case of sand and was inactive with silt loam. When potassium chloride was added to

the silt loam the salt was detected 1 inch away after 10 days and had proceeded 3 inches at the end of 20 days. Sodium carbonate moved but 1 inch in 20 days. In sand, the potassium chloride moved but 1 inch in 20 days although the concentration of this layer increased throughout the period. The sodium carbonate moved 1 inch in 10 days and showed traces 2 inches away at the end of 20 days. Thus, salts vary in their action in different soils.

Salts tend to set up two systems in a column of soil. One system is the movement of moisture toward the salt deposit and the other is the movement

TABLE 2

Movements of salts and moisture in silt loam at 2 per cent moisture and sand at 0.5 per cent moisture

DISTANCE FROM SALT LAYER	SILT LOAM				SAND			
	After 10 days		After 20 days		After 10 days		After 20 days	
	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content
inches	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*
2 grams KCl added								
4	0.005	2.39	0.007	2.93	0.002	0.30	0.003	0.35
3	0.006	2.45	0.030	3.10	0.003	0.32	0.003	0.38
2	0.005	2.32	0.025	2.91	0.003	0.34	0.004	0.35
1	0.150	3.46	0.390	5.10	0.160	0.34	0.290	0.88
1	0.840	3.86	1.040	4.72	0.110	0.96	0.250	0.92
2	0.002	2.33	0.022	2.50	0.003	0.42	0.005	0.40
3	0.004	2.60	0.020	2.71	0.002	0.30	0.003	0.39
4	0.004	2.62	0.004	2.71	0.003	0.40	0.003	0.41
2 grams Na_2CO_3 added								
4	0.005	2.68	0.004	3.12	0.002	0.52	0.003	0.41
3	0.006	2.90	0.006	3.15	0.003	0.56	0.004	0.45
2	0.006	2.75	0.007	3.04	0.003	0.54	0.010	0.46
1	0.050	3.17	0.040	3.65	0.130	0.78	0.200	0.71
1	0.070	2.78	0.180	3.74	0.110	0.58	0.140	0.77
2	0.006	2.68	0.008	2.96	0.003	0.48	0.006	0.49
3	0.005	2.78	0.004	3.15	0.004	0.60	0.002	0.40
4	0.005	2.70	0.004	3.10	0.002	0.52	0.002	0.40

of the salt into the surrounding medium. The water movement, if rapid and of capillary form, must retard somewhat the movement of the salt. On the other hand, the increase of moisture in any zone tends to increase the rate of salt translocation by the capillary movement outward. The salt deposit appears to attract moisture, which causes the salt to go into solution and aids in its translocation.

Table 3 shows the data from the treatment of silt loam at 4 per cent moisture, and medium sand at 1 per cent moisture, with potassium chloride and sodium

carbonate respectively. These data show very clearly in all cases the movement of water toward the salt deposits, and by comparison of these movements with those in table 2, it seems evident that the increased moisture present accomplishes greater salt and water movements. This is perhaps due to the greater number of contacts, and to the greater continuity of the films around the particles of the column. The salt solution in the vicinity of the deposit is doubtless a very concentrated one, and its surface tension is then markedly increased. The solution surrounding the soil in the outer layers is less concentrated, and, therefore, has a much lower surface tension. If there

TABLE 3

Movements of salt and moisture in silt loam at 4 per cent moisture and sand at 1 per cent moisture

DISTANCE FROM SALT LAYER	SILT LOAM				SAND			
	After 10 days		After 20 days		After 10 days		After 20 days	
	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content
inches	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*
				2 grams KCl added				
4	0.004	4.59	0.003	3.85	0.003	0.73	0.002	0.43
3	0.005	4.38	0.005	3.75	0.005	0.62	0.005	0.44
2	0.030	3.56	0.020	3.55	0.007	0.50	0.090	0.50
1	1.260	7.12	1.230	6.51	0.120	1.22	0.570	1.21
2	0.020	3.51	0.530	5.03	0.010	0.79	0.140	0.61
3	0.006	4.19	0.010	3.29	0.005	0.56	0.005	0.39
4	0.005	4.31	0.006	3.45	0.005	0.56	0.002	0.33
				2 grams Na_2CO_3 added				
4	0.005	4.91	0.003	2.27	0.004	0.90	0.002	0.65
3	0.005	4.84	0.004	2.37	0.003	0.86	0.002	0.65
2	0.006	4.28	0.015	4.03	0.004	0.72	0.003	0.60
1	0.160	6.58	0.140	6.15	0.090	1.65	0.360	1.18
1	0.210	5.48	0.220	6.15	0.080	1.61	0.330	1.89
2	0.006	4.09	0.010	3.72	0.004	0.67	0.010	0.51
3	0.005	4.57	0.005	3.73	0.003	0.66	0.004	0.54
4	0.004	4.59	0.003	3.79	0.003	0.70	0.002	0.56

is a continuous contact between these solutions the one with salt and the greater surface tension will withdraw moisture from the other. This perhaps explains why the water collects around the salt deposits. At the same time the salt solutions are diffusing outward into the soil. Experiments run over long periods of time result in a uniform concentration of the soil solution for all sections of the columns. The data of table 3 show that in silt loam at 4 per cent moisture content, potassium chloride has greater water-pulling power than sodium carbonate. In sand, however, sodium carbonate is greater, at the 10-day period. The potassium chloride shows greater activity throughout the

series, and seems less influenced by the movement of the water against it, since it has often moved out 3 inches, while only the first inch from the salt deposit shows any increase in moisture content. The sodium carbonate seems to be more localized and remains in the zone of high moisture content. The cause of these variations possibly may be explained by relative solubilities or differences in the mobility of ions.

Table 4 shows that when potassium chloride was placed in contact with silt loam at 6 per cent moisture and with medium sand at 2 per cent moisture the

TABLE 4

Movements of salts and moisture in silt loam at 6 per cent moisture and sand at 2 per cent moisture

DISTANCE FROM SALT LAYER	SILT LOAM				SAND			
	After 10 days		After 20 days		After 10 days		After 20 days	
	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content
inches	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*
2 grams KCl added								
4	0.005	6.69	0.007	5.82	0.006	2.13	0.140	2.04
3	0.015	6.91	0.090	6.74	0.050	2.20	0.210	2.06
2	0.190	6.93	0.490	7.11	0.440	2.19	0.320	2.07
1	0.980	7.64	0.920	7.22	0.390	2.23	0.650	2.14
1	1.185	7.50	0.980	7.56	0.370	2.13	0.360	2.13
2	0.330	6.89	0.580	7.04	0.415	2.11	0.290	2.13
3	0.015	6.51	0.190	6.53	0.085	2.12	0.320	2.09
4	0.010	6.36	0.020	6.29	0.005	2.10	0.150	2.04
2 grams Na_2CO_3 added								
4	0.004	6.19	0.004	6.15	0.002	1.92	0.004	1.64
3	0.005	6.20	0.004	6.07	0.010	1.92	0.010	1.86
2	0.008	5.79	0.005	5.63	0.050	1.99	0.105	2.13
1	0.105	8.30	0.290	9.73	0.460	3.05	0.370	3.37
1	0.300	8.75	0.190	8.45	0.650	3.10	0.510	3.29
2	0.008	5.77	0.003	3.57	0.030	1.91	0.090	1.82
3	0.006	6.16	0.004	5.80	0.004	1.94	0.010	1.52
4	0.005	6.19	0.005	5.81	0.002	1.89	0.005	1.53

water-pulling capacity of the salt, which was very noticeable from the results given in table 3, seemed to be changed. The zone immediately surrounding the salt deposit held but little more water than the other sections of the column, and in sand the layers throughout were almost uniform in moisture content. A very marked movement of salt occurred, however, probably because of the better contact between all particles, and the fact that there was undoubtedly a faster rate of solution of the salt resulting from more water being present. The sodium carbonate still showed power to attract water in both soils, but the movement of salt was very limited, and confined to the zone of high moisture

content as before. A consideration of the data given in table 5 is also interesting in this respect. It was found that no appreciable variation in the moisture contents of the different sections could be detected for either salt in silt loam at 10 per cent moisture. In sand with 3 per cent moisture the potassium chloride gave analogous results, but the sodium carbonate still increased the water content in the first inch. Moreover, the sodium carbonate moved 3 inches in 20 days, which is a notable increase over its movement at other water contents. The potassium chloride was again more active than it was under the

TABLE 5

Movements of salts and moisture in silt loam at 10 per cent moisture and sand at 3 per cent moisture

DISTANCE FROM SALT LAYER	SILT LOAM				SAND			
	After 10 days		After 20 days		After 10 days		After 20 days	
	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content
inches	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*
2 grams KCl added								
4	0.006	8.72	0.018	8.63	0.006	3.17	0.013	3.14
3	0.020	8.81	0.200	8.74	0.007	3.21	0.096	3.10
2	0.165	8.92	0.561	8.67	0.138	3.16	0.214	2.98
1	0.480	8.64	1.105	8.69	0.274	3.00	0.277	2.95
1	0.620	8.71	1.216	8.80	0.360	2.94	0.282	2.97
2	0.216	8.80	0.420	8.82	0.048	3.11	0.141	2.98
3	0.030	8.68	0.105	8.79	0.005	3.17	0.113	2.93
4	0.008	8.73	0.060	8.70	0.002	3.06	0.015	3.03
2 grams Na_2CO_3 added								
4	0.003	8.90	0.004	9.01	0.002	2.79	0.003	1.54
3	0.008	8.92	0.005	8.96	0.005	2.78	0.007	1.56
2	0.020	8.88	0.040	8.80	0.010	2.79	0.018	1.41
1	0.020	8.96	0.810	8.87	0.303	3.80	0.225	4.42
1	0.810	8.70	1.050	8.94	0.225	3.92	0.279	4.80
2	0.018	8.84	0.30	8.92	0.005	2.82	0.029	2.04
3	0.006	8.78	0.007	8.85	0.005	2.86	0.008	1.98
4	0.006	8.80	0.008	8.75	0.002	2.89	0.006	1.99

conditions noted in table 4, and has been detected at the end of the tubes after 20 days, and 3 inches out at the end of 10 days. Both salts have moved farther with these moisture contents than with any preceding ones.

As a final series, the soils were made up to high moisture contents, 9 per cent being placed in sand, and 20 per cent in silt loam. The data are given in table 6, and when compared with table 5, show but little if any increase in the amount or distance that the salt has moved. It may be safely said then, that at 3 per cent moisture in sand, and at 10 per cent moisture in silt loam, the maximum activity has been reached, and further additions of moisture have but

a slight effect in hastening the movements. At 9 per cent moisture in sand, the sodium carbonate did not increase the moisture immediately around the deposit.

The data from the entire series as presented in the six tables show that the amount and speed of salt translocation increase with the increase of moisture content up to a certain point, after which other additions have little effect; that there is a moisture condition where the maximum amount of moisture is drawn around the salt, and at all higher moisture contents this activity does not

TABLE 6

Movements of salts and moisture in silt loam at 20 per cent moisture and sand at 9 per cent moisture

DISTANCE FROM SALT LAYER	SILT LOAM				SAND			
	After 10 days		After 20 days		After 10 days		After 20 days	
	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content	Freezing point lowering	Moisture content
inches	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*	°C.	*per cent*
2 grams KCl added								
4	0.006	17.24	0.075	17.13	0.006	7.95	0.085	7.87
3	0.050	17.30	0.148	16.94	0.050	8.00	0.251	7.88
2	0.180	17.48	0.321	17.10	0.280	8.02	0.493	7.51
1	0.840	17.22	1.050	17.20	0.535	7.55	0.691	7.56
1	0.750	17.34	0.970	17.04	0.497	7.69	0.568	7.36
2	0.220	17.30	0.284	17.19	0.214	8.32	0.335	7.68
3	0.102	17.41	0.106	17.25	0.007	8.29	0.117	8.06
4	0.006	17.08	0.040	17.30	0.003	8.20	0.081	7.85
2 grams Na_2CO_3 added								
4	0.004	18.02	0.005	17.91	0.004	8.41	0.002	8.62
3	0.005	17.96	0.018	17.94	0.004	8.33	0.013	8.48
2	0.008	17.84	0.162	17.70	0.029	8.45	0.055	8.04
1	0.529	17.60	0.614	17.74	0.343	7.62	0.220	7.82
1	0.642	17.71	0.636	17.59	0.325	7.69	0.415	7.79
2	0.010	17.86	0.184	17.79	0.027	8.40	0.115	7.80
3	0.008	17.91	0.014	17.70	0.004	8.58	0.015	8.56
4	0.004	17.89	0.005	17.90	0.003	8.62	0.005	8.78

exist; that the texture of the medium has but little effect in causing variations in salt and water movements; and that salts vary in their mobility, for, in this study, potassium chloride was much more active than sodium carbonate.

Theoretical considerations of these facts lead one to believe that the reasons underlying the increase in the amount and speed of movement up to a certain maximum point, are to be found in the solubilities of the salts. It is generally recognized that soluble salts will go into solution fast at first, but as the concentration of the solution increases, the rate of solution decreases. In the soil containing but 0.5 per cent of water the total amount of salt really in solution

is small, as compared with the total amount in solution with the soil at 3 per cent moisture. Thus, in the latter case, more salt being active, a greater potential is created, and greater movement follows. Further additions of moisture do not increase the total movement because the lower percentage is sufficient completely to dissolve the salt, and the added water dilutes the diffusing solution so that its rate is decreased. This is tenable from the fact that the movement of salt to water from a strong concentration is greater than the same movement from a weak concentration. Thus it seems that the whole phenomenon may be explained upon the basis of solubilities.

A corresponding line of reasoning may be employed in the explanation of the water-pulling capacities. At low moisture contents, the concentration around the salt deposit becomes great, since undoubtedly a saturated solution is produced. This has a strong attractive force, due to its increased surface tension, and draws more moisture from the surrounding layers. This water in the adjacent layers is, however, held with considerable tenacity and the saturated solution can obtain only a part of what it requires. But, upon the use of more water more becomes available and movable while the solution of salt is still saturated. Hence, a greater amount will be withdrawn in the second case. Additions of water tend to increase the ease with which the water moves from place to place, while it still produces a saturated solution for the tractive agent. Finally when past the maximum, the salt becomes entirely dissolved and only a weak solution results. Its pulling power is thus reduced. Since sodium carbonate is somewhat less soluble than potassium chloride, it continues to produce a saturated solution for a longer period and exerts its pulling power longer.

The influence of texture seems negligible. The moisture contents employed are, roughly, multiples of the hygroscopic coefficient. For example, the air-dry sand held about 0.25 per cent of water, while air-dry silt loam had about 1.5 per cent moisture. The next series of sand contained an average of 0.58 per cent or roughly twice the air-dry water content. Also the silt loam held on the average, about 2.9 per cent moisture which is again approximately twice the first moisture content. This has been carried on in connection with the other experiment, making proportional amounts of water in the soils of different texture. Yet there are no appreciable differences in the activities of these two soils.

It is well known that sodium carbonate has a harmful effect on structural conditions in heavy soils. The slower rate of diffusion and of water movement in these experiments may be somewhat influenced by the poor structural condition of the soil in the sodium carbonate tubes. In medium sand, however, little influence would be visible and yet the movements of salt and moisture in the silt loam soil were remarkably comparable to the sand in all cases. The structure of the soil as influenced by the added salt thus seems to be of minor importance.

The greater activity of potassium chloride is probably due to two properties

in which it surpasses sodium carbonate. It is more readily soluble in water, and has a greater solubility product. Also its ions possess greater mobility. The solubility of potassium chloride in water is 25.4 gm. in 100 gm. of solution at 20°C. While under the same conditions sodium carbonate solution contains only 17.7 gm. per 100 gm. of solution. The mobility of the potassium ion is given by Kohlraush as 2.05 while the mobility of the sodium ion is 1.25 at 18°C. The mobility of the chlorine ion is 2.12 while that of the carbonate ion is 1.89. Total molecular mobility for potassium chloride is then, 4.19, while for sodium carbonate it is only 3.15.

II. The strength of the attraction of salt for moisture

A natural force which could be employed readily as a measurement of the pull of sodium carbonate for soil moisture was the force of capillarity. Consequently a series of tubes (8 inches by $1\frac{7}{8}$ inches) was arranged in which two soils were used, a medium sand and a clay loam. Two tubes of each soil were prepared by placing 2 gm. of finely powdered sodium carbonate in the bottom inch of moist soil and filling up the remainder of the cylinders with moist soil. One of these was left open at the top, but closed with melted paraffin at the bottom or salt end. The other tube of each soil was paraffined so that both ends were closed to allow no evaporation. One tube of each soil was then filled to the top without using any salt and sealed at the lower end only. At the expiration of 5 days the series was sampled by dividing the core into 1-inch sections from top to bottom. A portion of each section was air-dried and used for freezing point determinations, and the moisture content of the remainder was determined using aluminum cans and drying in an oven at 103°C. for about 48 hours. The results of this experiment are reported in table 7.

These data show that the attraction of the salt for the soil moisture is stronger than the force of capillarity, which is tending to draw the moisture upward toward the evaporating surface. In the case of the sand in the tube containing no salt, with an evaporating surface at the top, there is a steady increase in moisture from the surface downward. The first 3 inches of the open, salt-treated tube are similar to the above, but at this point the influence of the attraction of salt becomes noticeable and the moisture content of the other layers up to the salt layer are much less than in the untreated soil. The force of the salt attraction alone may be seen in the third tube which is closed at the top. Again there has been a decrease in the moisture content, especially in the second inch away from the salt layer. In both salt-treated tubes there was a movement of salt outward about 1 inch during this 5-day period, as is shown by the freezing point depressions. There was less activity observable in the clay loam series, both in moisture and in salt movements. The more sluggish capillarity in the finer textured soil may be the reason for the slow action. The results of this experiment lead one to conclude that a salt when placed in a soil will draw moisture to itself against the action of

capillary rise due to evaporation. There must exist, therefore, an appreciable attractive force of a salt for water.

III. The effects of air space in soil upon the movement of moisture from water-treated to salt-treated soils

Glass tubes 8 inches by $1\frac{7}{8}$ inches in size were used in this series, and the salt-treated soil separated from the water-treated soil by means of a double screen. There was about a $\frac{1}{2}$-inch space separating the two columns. The salt-treated soil contained 1 per cent potassium chloride or 1 per cent sodium carbonate by

TABLE 7

Percentage of moisture and freezing point depressions after 5 days using sodium carbonate

DISTANCE FROM SALT LAYER	H_2O OPEN		Na_2CO_3 OPEN		Na_2CO_3 CLOSED	
	*FPD	H_2O	FPD	H_2O	FPD	H_2O
inches	*°C.*	*per cent*	*°C.*	*per cent*	*°C.*	*per cent*
Medium sand—1.70 per cent moisture at start						
7	0.009	0.26		0.24		1.43
6		0.53		0.50		1.58
5		1.29		1.09		1.66
4	0.003	1.58		1.28		1.64
3		1.58		1.30	0.003	1.58
2		1.63	0.003	1.02	0.014	1.35
1		1.73	0.425	2.18	0.320	1.94
0	0.003	1.78	0.765	3.20	0.650	2.85
Clay loam—21.83 per cent moisture at start						
7	0.009	8.70	0.009	8.48	0.009	21.60
6		16.92		16.46		22.12
5		19.78		19.11		21.77
4	0.006	20.03		20.34	0.009	21.67
3		21.28	0.007	20.41	0.017	21.06
2		21.33	0.022	20.38	0.027	21.55
1		21.58	0.762	23.10	0.932	23.80
0	0.007	21.20	1.292	21.92	1.230	21.73

* Freezing point depression.

weight and was made up to the same moisture content as the soil with water alone. For each water content there was provided a tube with the salt-treated and water-treated soils in contact, and another tube, in which the two components of the system were separated by the $\frac{1}{2}$-inch air space. After having been stored at 18°C. for intervals of 5 and 15 days, the tubes were sampled in 1-inch sections, and a portion air-dried. Moisture determinations as well as freezing point determinations were made on all sections. There were no salt movements, of course, in the tubes with air spaces, but the usual movement took place in the contact tubes. The moisture contents alone are given in table 8.

TABLE 8

Movements of moisture in medium sand and clay loam resulting from the separation of a 1 per cent KCl and a 1 per cent Na_2CO_3 salt-treated soil from a water-treated soil by a one-half inch air space

DISTANCE FROM SALT LAYER	BROKEN COLUMN		CONTINUOUS COLUMN	
	5 days	15 days	5 days	15 days
inches	*per cent*	*per cent*	*per cent*	*per cent*
	Medium sand and potassium chloride			
6	2.89	1.84	2.97	2.80
5	2.85	1.85	2.94	2.77
4	2.70	1.78	2.94	2.77
3	2.56	1.69	2.93	2.74
2	2.41	1.54	2.86	2.72
1	2.27	1.32	2.76	2.72
0	3.93	7.42	2.58	2.68
0	3.58	7.38	2.53	2.53
	Medium sand and sodium carbonate			
6	3.43	3.11	3.45	2.96
5	3.48	3.12	3.47	3.09
4	3.47	3.26	3.52	3.13
3	3.49	3.35	3.40	3.35
2	3.44	3.29	3.35	3.29
1	3.37	2.33	3.28	3.46
0	5.23	6.14	3.61	3.70
0	4.95	6.07	3.58	3.88
	Clay loam and potassium chloride			
6	20.39	20.34	20.75	20.14
5	20.71	20.35	20.63	20.36
4	20.72	20.08	21.02	21.02
3	20.32	19.95	20.95	20.74
2	20.08	19.53	20.96	20.96
1	19.84	19.14	20.48	20.21
0	21.52	23.25	20.08	19.80
0	21.24	23.35	19.96	19.70
	Clay loam and sodium carbonate			
6	19.87	19.60	19.22	18.72
5	20.02	19.76	19.26	18.70
4	20.09	19.74	19.34	18.62
3	20.28	19.77	19.36	19.23
2	20.02	19.64	19.47	19.41
1	19.94	19.51	19.70	19.91
0	20.58	21.06	20.02	20.41
0	20.52	21.02	20.09	20.51

There was a rapid distillation of vapor across the air space in sand, for both salts used, and the amount that passed across increased with the time which the tubes were allowed to stand. At the end of 15 days, the maximum amount of vapor that could pass over had probably not done so, and it is likely that the water would continue to collect in the salt layer until the salt had been completely dissolved. In tubes with the salt in contact with the soil, there was little movement of water which could be detected except in the case of sodium carbonate. It may be, however, that a movement of vapor took place between the two components, as before, but the increase in the salt layer, due to the condensation of the vapor, was taken care of by the continuity of the capillary water, which would allow a readjustment as soon as one portion of the tube held more water than another. As a consequence there was probably a stream of vapor passing from the water solution to the salt solution in each case. But with an air space, as there was no chance for a readjustment of the film, a steady increase was recorded. In the other case, the readjustment through the entire column was possible.

The presence of a salt solution as one component of the system, provides for a higher surface tension and a lower vapor pressure, than is found in the other component, which is a rather weak soil solution. This inequality starts the movement of vapor from a point of high pressure to one of low pressure. As long as the salt solution remains saturated the movement will probably continue at about the same rate.

The magnitude of the movements is somewhat influenced by texture, the heavier soil being more sluggish in its action. Eventually, however, there is little doubt that a large movement of vapor would have taken place in the clay loam.

The magnitude of the vapor movement of soil moisture has been little realized, yet it may play an important part in the nourishing of plants, in the distribution of fertilizers, and in physical conditions in soils.

SUMMARY

1. Experiments concerning the mutual effects of salts and moisture added to soils of different texture have been presented.

2. There were no salt movements in soils containing only their hygroscopic moisture.

3. Increasing the moisture content increases the rate and amount of salt translocation up to a certain point, after which further additions of water show no increasing effects.

4. For medium sand the point of maximum salt movement occurred at a moisture content of about 3 per cent, for silt loam at about 10 per cent.

5. An undissolved salt such as sodium carbonate has a strong attraction for soil moisture. This force was stronger than the force of capillarity which tends to draw water upward toward the evaporating surface.

6. There is a marked and important movement of soil moisture, as a vapor, toward a salt-treated soil. Where capillary connection is cut off, this causes an accumulation of water around the salt. The vapor movement of moisture in soils is undoubtedly important.

REFERENCES

(1) BOUYOUCOS, G. J., AND MCCOOL, M. M. 1916 Further studies on the freezing point lowering of soils. Mich. Agr. Exp. Sta. Tech. Bul. 31.

(2) MCCOOL, M. M., AND WHEETING, L. C. 1917 Movement of soluble salts through soils. *In* Jour. Agr. Res., v. 11, no. 11, p. 531–547.

THE RELATION OF FUNGI TO THE NUMBERS OF BACTERIA IN THE SOIL[1]

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Soil bacteria, actinomycetes and fungi are the chief agents in transforming the unavailable carbonaceous and nitrogenous substances in the soil into forms assimilable by higher plants. Each of these groups, and frequently different representatives of these groups have different physiological functions and consequently may bear a definite relationship to representatives of the other groups and to the protozoa, nematodes, algae, insects and other organisms present in the soil. Very little is known about these relationships existing between the different groups of soil organisms.

In the course of their study on the influence of partial sterilization upon the distribution and activities of microörganisms in the soil, Waksman and Starkey (14) observed that there was no seemingly direct correlation, except in one or two instances, between the repression and later development of protozoa and bacterial development in the soil; there was, however, a certain correlation between the development of bacteria and the filamentous fungi in the soil. They did not claim that the development of the fungi in the soil had a depressing action upon the development of bacteria; they suggested, however, that the numbers of bacteria are governed by the balance of microorganisms in the soil, including the fungi and actinomycetes and perhaps the protozoa. Under the circumstances, it was decided that further information on the relationship existing between the heterotrophic bacteria and the filamentous fungi might be obtained by inoculating partially sterilized soils with pure cultures of soil fungi or with soil suspensions of the untreated soil and observing the influence of the introduced fungi upon the numbers of bacteria surviving the sterilization process.

The initial experiment, dealing with the influence of the concentration of carbon disulfide upon the numbers of bacteria and fungi, was conducted to determine the amount of this compound necessary to suppress the fungous

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flora normally present in the soil.[2] Sassafras loamy sand was weighed out, in duplicate kilogram samples, into glass jars and treated with 0.1, 0.4, 1.6 and 6.4 per cent, respectively, of carbon disulfide, two jars being left untreated in order to trace the normal microbiological fluctuations over the period of observation. The jars were tighty closed with metal covers and allowed to stand for 48 hours. After the vapors of the antiseptic had been in contact with the soil for this period of time, samples of soil were carefully withdrawn to determine the numbers of fungi and bacteria present,[3] and the tight covers were replaced with sterile cotton plugs to permit the antiseptic to evaporate from the soil and, at the same time, to prevent contamination of the soils with bacteria and fungi floating in the laboratory air. At the end of 2 weeks, when the carbon disulfide had disappeared from all the jars, enough sterile distilled water was added to bring the soils to the optimum moisture, and the jars were resealed with sterile metal covers.

TABLE 1

Effect of addition of different amounts of carbon disulfide on the bacteria and fungi in the soil

PERIOD AFTER TREATMENT	0.1 PER CENT		0.4 PER CENT		1.6 PER CENT		6.4 PER CENT		CONTROL	
	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi
days	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*
0	4.5	28.6	1.9	0.0	1.2	0.0	1.0	0.0	3.1	32.0
90	2.4	32.3	3.2	0.0	2.0	0.0	2.2	0.0	2.8	26.3

Bact.—numbers of bacteria developing on the plate per gram of moist soil.
Fungi—numbers of fungi developing on the plate per gram of moist soil.
m.—million.
t.—thousand.

The fungi and bacteria (including the actinomycetes) were determined in the samples of soil taken at the end of the sterilization period and again 90 days subsequent to the treatment; 1:10 and 1:100 dilutions of the soil were used for fungi, while the bacteria were determined at the same time with a dilution of 1:100,000. The results of these determinations, summarized in table 1, indicate that a concentration of 0.4 per cent carbon disulfide is sufficient to suppress the fungi in this particular type of soil. The heterotrophic bacteria developing on the plates were reduced in numbers, but for some reason, possibly due to a limitation in the available nutrients, did not, subsequent to the

[2] One of the soils used for these observations was a sassafras loamy sand from Riverton New Jersey, containing 2.5 per cent organic matter, as determined by ignition at red heat and the other was a rich greenhouse soil from New Brunswick, New Jersey. Both soils were air-dried, sifted and stored in suitable closed containers where sufficient water was added to maintain them at the optimum moisture content.

[3] The numbers of bacteria were determined by the plate method described by Waksman and Fred (13), using 5 plates and incubating at 25°–28°C. for 7 days; the numbers of fungi were determined also by the plate method using the special medium recommended by Waksman (12). The ammonia was determined by distillation with magnesium oxide.

treatment, increase greatly in numbers as was expected according to the results obtained by Hiltner and Störmer (3), Russell (8), Russell and Hutchinson (10), Fred (1), Scherpe (11) Waksman (14), and others. It was also expected that some fungi would have developed in the partially sterilized soil at the end of the 90-day period, since, as noted by Kurzwelly (4), the spores of fungi are able to withstand various concentrations of carbon bisulfide. The 0.1 per cent concentration of the antiseptic did not seem sufficient to change greatly the fungous or bacterial flora in the soil. As a result of these observations, it was concluded that 2 per cent carbon disulfide would be ample to suppress the natural soil fungi present in the loamy sand and in the greenhouse soil before inoculating these soils with the fungous suspensions.

TABLE 2

Treatment of cultures

CULTURE NUMBER	SOIL	ORGANISMS ADDED SUSPENDED IN WATER	REMARKS
1	Loamy sand	*Penicillium* sp.	Sterilized before inoculation
2	Loamy sand	*Trichoderma* sp.	Sterilized before inoculation
3	Loamy sand	*Penicillium* sp. + *Trichoderma* sp. + *Fusarium* sp. + *Aspergillus fumigatus*	Sterilized before inoculation
4	Loamy sand	Soil suspension	Sterilized before inoculation
5	Loamy sand	None	Sterilized but only water added
6	Loamy sand	None	Untreated soil
7	Greenhouse	*Zygorhynchus* sp.	Sterilized before inoculation
8	Greenhouse	*Trichoderma* sp.	Sterilized before inoculation
9	Greenhouse	*Trichoderma* sp. + *Penicillium* sp. + *Aspergillus* niger + *Zygorhynchus* sp.	Sterilized before inoculation
10	Greenhouse	Soil suspension	Sterilized before inoculation
11	Greenhouse	None	Sterilized but only water added
12	Greenhouse	None	Untreated soil

Kilogram quantities of the loamy sand and the greenhouse soil were placed, therefore, in glass jars and prepared for inoculation by treating with 2 per cent carbon disulfide as outlined in the initial experiment. When the antiseptic had disappeared from the jars, the partially sterilized soils were inoculated, in duplicate series, with 25 cc. of water containing either a soil suspension or cultures of fungi in suspension. These jars with the necessary uninoculated jars, the compositions of which are detailed in table 2, were kept under optimum moisture conditions in the laboratory by adding sterile distilled water as needed and were examined at intervals to determine the numbers of fungi and bacteria in each.

The determinations on the untreated sassafras loamy sand (culture 6, table 3) showed a uniform bacterial and fungous flora throughout the period, indi-

cating that during the 6 months storage, prior to the observations, the soil had attained a certain biological balance or unstable equilibrium. Waksman and Starkey (14) found that it was necessary to store their sassafras loam for 175 days before the bacteria and actinomycetes came to a level where the decrease or increase in numbers was only very slow, while this equilibrium was attained by the fungi only after 250 days. The numbers of fungi and bacteria in the

TABLE 3

Numbers of bacteria and fungi developing in cultures of sassafras loamy sand

PERIOD AFTER TREATMENT	CULTURE 1		CULTURE 2		CULTURE 3		CULTURE 4		CULTURE 5		CULTURE 6	
	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi
days	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*
0	0.8	2.0	0.6	5.1	0.6	6.0	0.7	0.0	0.6	0.0	2.9	34.0
7	1.5	4.0	0.8	28.0	0.7	38.0	1.1	0.0	1.3	0.0	2.7	20.0
19	1.8	34.0	1.0	80.0	1.0	102.0	2.0	0.0	1.2	1.0	3.1	24.0
35	..	65.0	...	83 0	...	275.0	...	11.0	...	2.0	...	21.0
42	1.7	112.0	1.1	132.0	0.8	152.0	2.3	10.0	1.5	4.0	2.8	22.0
63	2.2	250.0	1.8	164.0	1.4	198.0	2.3	78.0	1.8	117.0	3.4	34.0

Bact.—colonies of bacteria per gram of moist soil.
Fungi—colonies of fungi per gram of moist soil.
m.—millions.
t.—thousands.

TABLE 4

Numbers of bacteria and fungi developing in cultures of greenhouse soil

PERIOD AFTER TREATMENT	CULTURE 7		CULTURE 8		CULTURE 9		CULTURE 10		CULTURE 11		CULTURE 12	
	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi	Bact.	Fungi
days	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*	*m.*	*t.*
untreated									17.5	46.0	15.5	46.0
0	12.0	5.5	11 8	8.3	16.0	29.0	11.8	0.0	12.9	0.0	10.0	46.0
17	15 6	4.3	18.7	25.6	21.5	52.0	24.1	0.0	19 3	0 0	11 8	41 0
31	23 8	18.1	28.9	58.0	30.0	75.0	43.0	1.5	24.1	0.5	7.6	25.0
45	43.2	11.1	25.9	80.0	24.5	82.0	38.9	2.0	24.7	0.7	4.0	26.0
71	37.9	12.0	25.6	38.0	30.4	52.6	34.1	1.2	33.8	5.3	7.2	18.0

Bact.—colonies of bacteria per gram of moist soil.
Fungi—colonies of fungi per gram of moist soil
m.—millions
t.—thousands

fresh greenhouse soil (culture 12, table 4) gradually decreased so that after 71 days there were only one-half those in the initial determination. This soil, however, had not reached an unstable equilibrium between the organisms and the other constituents. During the 4-week period when the soil was being composted with manure, the activities of the organism were very high; the air-drying and sieving, followed by moistening with water to bring the soil

back to optimum moisture, also had a decidedly stimulating effect upon the numbers and activities of the bacteria and fungi, as has also been observed by Rahn (6), Ritter (7), Waksman and Starkey (14) and others. This stimulation of the organisms, both in the composting and in the drying, would be followed naturally by a gradual decrease in the numbers and activities of the organisms until a more stable equilibrium was established.

As was anticipated from the initial experiment to determine the amount of carbon disulfide necessary to suppress the normal fungous flora, it was found that 2 per cent of this compound was ample to eliminate temporarily the fungi normally present in the loamy sand and in the greenhouse soil (cultures 5 and 11). It is realized that this poccess of sterilization with carbon disulfide destroyed, injured or at least modified the activities of the fungi, some actinomycetes, the protozoa, and some bacteria, and modified the chemical and physical conditions of the soil to some extent. No better procedure, however, was known to prepare the soil for the inoculation with a known quantity of one or more pure cultures of a particular soil fungus. Since the soil is made more or less artificial by this treatment, the results obtained from these inoculations may not apply directly to the elucidation of the normal soil processes, but they are indicative of the relationship existing between these two groups of organisms.

The inoculation of the carbon disulfide treated soils with a suspension of the normal soil flora (cultures 4 and 10) stimulated the development of the heterotrophic bacteria and hastened the recovery of the filamentous fungi.

When pure fungous suspensions were used to inoculate the soils, the subsequent development of the fungi was more vigorous and rapid than in the soils inoculated with the soil suspension. In the loamy sand, *Trichoderma* (culture 2) seemed to withdraw the available energy from the soil to such an extent as to inhibit the rapid development of the heterotrophic bacteria but where there was an abundant supply of energy (culture 8) this fungus apparently did not affect the growth of the bacteria. The results obtained with mixtures of pure fungi (cultures 3 and 9) and with single pure cultures of *Penicillium* (culture 1) and *Zyorhychus* (culture 7) were in close agreement with those obtained with *Trichoderma*.

The results of these determinations seem to indicate that the reëstablishment and subsequent development of a group of bacteria or fungi in the soil are dependent primarily upon the suitableness of the soil environment for the growth of the organisms. The treatment of the rich soil with carbon disulfide stimulated the development of large numbers of heterotrophic bacteria, as was expected, in view of the results obtained in this and other laboratories. But it was not expected that the stimulation of bacteria in the rich soil would be practically independent of the vigor of the fungous flora. The partially sterilized soil which was not re-inoculated and in which the fungi were very slow in reëstablishing themselves, passed through the same increase in bacterial numbers as those soils inoculated with a soil suspension, with *Zygorhyn-*

chus, with *Trichoderma* or with a mixture of pure cultures of soil fungi. In the relatively poor soil, the same relationship existed, only the density of the bacteriological population was much lower. The development of the fungi seemed to be closely related to the vigor of the cultures at the time of inoculation and to the ability of the organism to utilize the available energy in the soil. In spite of the known bactericidal action of certain species of fungi (5, 14), there was no indication, in these experiments, which would lead one to conclude that the fungi in the soil had a depressing action on the development of the heterotrophic bacteria, especially when large quantities of available organic matter were present.

TABLE 5

Free ammonia nitrogen in sassafras loamy sand

PERIOD AFTER TREATMENT	AMMONIA NITROGEN IN 100 GRAMS OF SOIL					
	Culture 1	Culture 2	Culture 3	Culture 4	Culture 5	Culture 6
days	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
50	2.8	2.8	3.5	3.2	2.1	0.0

TABLE 6

Free ammonia nitrogen in greenhouse soil

PERIOD AFTER TREATMENT	AMMONIA NITROGEN IN 100 GRAMS OF SOIL					
	Culture 7	Culture 8	Culture 9	Culture 10	Culture 11	Culture 12
days	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
20	7.0	6.3	5.6	7.6	5.3	2.7
100	5.6	6.3	7.3	2.8	2.8	2.8

SUMMARY AND CONCLUSIONS

In order to study the relation between the fungi and the numbers of bacteria, soils partially sterilized with 2 per cent carbon disulfide were inoculated with suspensions of untreated soil and with pure cultures of *Penicillium*, *Trichoderma*, *Aspergillus*, *Fusarium* and *Zygorhynchus*. The results of the determinations indicate that the development of bacteria is more dependent upon the available organic matter in the soil than upon the presence or absence of fungi. There was no indication that the filamentous fungi had a depressing action on the development of the heterotrophic bacteria, especially in the presence of an abundance of organic matter. The relative numbers of bacteria and fungi in the soil appeared to be governed largely by the ability of the organisms to utilize the energy present in the soil.

REFERENCES

(1) FRED, E. B. 1911 Über die Beschleunigung der Lebenstatigkeit höherer und niederer Pflanzen durch kleine Giftmengen. *In* Centbl. Bakt. (etc.), Abt. 2, v. 31, p. 185–245.

(2) FRED, E. B. 1916 Relation of carbon bisulphide to soil organisms and plant growth. *In* Jour. Agr. Res., v. 6, p. 1–19.

(3) HILTNER, L., AND STÖRMER, K. 1903 Studie über die Bakterienflora des Ackerbodens mit besonderer Berücksichtigung ihres Verhaltens nach einer Behandlung mit Schwefelkohlenstoff und nache Brache. *In* Arb. K. Gsndhtsamt., Biol. Abt., v. 3, p. 445–545.

(4) KURZWELLY, W. 1903 Über die Widerstandsfähigkeit trockener pflanzlicher Organisms gegen giftige Stoffe. *In* Jahrb. Wiss. Bot. (Pringsheim), v. 38, p. 291. *Abs. by* Kopeloff, N., and Coleman, D. A. 1917 A review of investigations in soil protozo and soil sterilization. *In* Soil Sci., v. 3, p. 197–269.

(5) NADSON, G. A., AND ZOLKIEWEIZ, A. I. 1922 Spicaria purpurogenes, n. sp. On the antagonism of microörganisms (Russian). *In* Bul. Jard. Bot. Repub. Russe., v. 21, add. 1, p. 1–18. *Cited by* Waksman and Starkey.

(6) RAHN, O. 1908 Bakteriologische Untersuchung über das Trocknen des Bodens. *In* Centbl. Bakt. (etc.), Abt. 2, v. 20, p. 38–61.

(7) RITTER, G. 1912 Das Troknen der Erden. *In* Centbl. Bakt. (etc.), Abt. 2, v. 33, p. 116–143.

(8) RUSSELL, E. J. 1913 The complexity of the microscopic population of the soil. *In* Science, n.s., v. 37, p. 519–522.

(9) RUSSELL, E. J., AND HUTCHINSON, H. B. 1909 The effect of partial sterilization of soil on the production of plant food. *In* Jour. Agr. Sci., v. 3, p. 111–144.

(10) RUSSELL, E. J., AND HUTCHINSON, H. B. 1913 The effect of partial sterilization on the production of plant food: II. The limitation of bacterial numbers in normal soil and its consequences. *In* Jour. Agr. Sci., v. 5, p. 152–221.

(11) SCHERPE, R. 1909 Über den Einfluss des Schwefelkohlenstoffs auf die Stickstoffumsetzungsvorgänge im Boden. *In* Arb. K. Gendhtsamt., Biol. Abt., v. 7, pt. 3, p. 353–428.

(12) WAKSMAN, S. A. 1922 A method for counting the numbers of fungi in the soil. *In* Jour. Bact., v. 7, p. 339–341.

(13) WAKSMAN, S. A., AND FRED, E. B. 1922 A tentative outline of the plate method for determining the number of microörganisms in the soil. *In* Soil Sci., v. 14, p. 27–28.

(14) WAKSMAN, S. A., AND STARKEY, R. L. 1923 Partial sterilization of soil, microbiological activities and soil fertility. *In* Soil Sci., v. 16, p. 137–157, 247–268, 343–357.

NITRATE LEACHINGS AS INFLUENCED BY CALCIC AND MAGNESIC ADDITIONS, WITH AND WITHOUT SULFUR CARRIERS

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It is generally accepted that liming of acid soils causes increased nitrification. Lyon and Bizzell (4) showed the outgo of nitrogen from a 4-foot soil depth to have been increased by surface applications of 3000 pounds of CaO to a Volusia soil. The reverse proved true with a Dunkirk soil (3). By differential analysis of total nitrogen, Mooers and MacIntire (9) showed the influence of several forms of lime and magnesia at two rates of application upon the nitrogen economy of both cropped and uncropped soil in embedded cylinders. In that study the nitrogen balance was subject to the additive factors of nitrogen increment from rainfall and fixation; but analyses of contemporaneously collected rainfall showed that the rainfall nitrogen was a minor and negligible factor. Fixation was apparently of considerable importance where plant growth was heavy.

This contribution deals with the outgo of nitrogen from a fallow surface soil as influenced by lime and magnesia in different forms and in varying amounts, with and without one of 3 forms of sulfur. The rainfall increment of nitrate and other forms of nitrogen was again a negligible factor. The influence of higher forms of plant growth was eliminated; however, the lower forms of plant growth, moss and lichens, may have been of some influence upon the nitrogen balance. While these possible vitiating factors were hardly constant, they were as nearly so as the experimental conditions would permit.

The data are not offered as absolute measures of nitrification, nor of removal of generated nitrates. It is possible that the alkali-earth treatments may have affected the soil's retentive properties, as well as its nitrate-generative capacity. Using sulfates as a measure for the same soil (8, p. 85) it has been shown that the outgo over a 5-year period was less than that of the laboratory extraction in a 1–5 aqueous suspension. However, Stevens and Withers (10) and Allen and Bonazzi (1) have shown that 1–5 extractions do not always remove nitrates from soil suspensions, while absorptive properties of various other solids have been studied by Tung (11). It is therefore necessary to consider the outgo of nitrates solely on the basis of surface soil losses found under the several imposed conditions.

EXPERIMENTAL

The soil, treatments, and installation of the twenty-two 1/20,000-acre embedded lysimeters have been described and illustrated in previous publications (7, p. 159, 6) which have dealt with losses of sulfates, calcium, magnesium, and potassium. The original total nitrogen content of the soil was 0.112 per cent. The losses of nitrate nitrogen were determined by analysis of each collection of leachings during the 6-year period of August, 1917 to August, 1923. The periodic, annual totals and 6-year period totals of nitrate losses for the 22 tanks are given in tables 1 to 7.

DISCUSSION OF RESULTS

First year. In comparing the 7 no-sulfur tanks (table 1), close parallel is shown between the limestone and dolomite treatments, both of which failed to give nitrate losses equal to the outgo from the control. The minimum burnt-lime addition likewise failed to cause appreciable increase in nitrate outgo, but the larger treatment caused an increase of 68 per cent, closely approximating that from its magnesia equivalent. Of the 4 minimum treatments, the MgO was the only one to show any decided increase in nitrification.

Four of the 5 ferrous sulfate treatments resulted in losses of nitrogen below the outgo from the untreated control, the greatest depression having been shown by the unsupplemented iron salt. Practical inhibition of nitrification was noted in the case of the heavy burnt-lime tank between installation in August, 1917 and April, 1918. During this period only 0.3 pound of nitrate nitrogen was leached from the heavily limed tank as against 17.9 pounds from the no-treatment control. It might be assumed that some nitrates were present at the time of the incorporation of the 32 tons of lime. If such were the case, it would appear that the lime was depressive both to the generation and leaching of nitrates.

Comparison of the sulfate control with the 4 basic supplements shows that all of the CaO and MgO treatments overcame the depressive tendency of the ferrous sulfate. This activity was not exerted by the heavy burnt-lime addition until the fifth interval between April 22 and August 3.

In the pyrite group the control also showed a depressive effect which again was overcome and reversed by the basic treatments, particularly at the 3750-pound rate. The same initial inhibition and subsequent increase shown by the heavy lime in the $FeSO_4$ group were found in the pyrite group. When compared with the group control, all 4 basic supplements show increased nitrate outgo, with MgO proving more active than CaO in this regard. It has been shown (7) that the alkali earth additions were repressive to the oxidation of the pyrite, hence the sulfate occurrences in this group were less than those of the ferrous sulfate group. This is reflected in comparisons between corresponding treatments which show the $FeSO_4$ additions to have been more depressive than pyrite upon nitrate outgo.

The losses from the elementary sulfur group are more nearly parallel with those of the ferrous sulfate than with those of the pyrite group. This is as would be expected, for the sulfur oxidation was so rapid (7) as to produce an

TABLE 1

Periodic and total losses of nitrate nitrogen from a loam soil during the first year after treatments of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT PER 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1917, TO AUGUST 3, 1918							
	Calcic-magnesic		Equivalence of 1000 pounds of S	Date of collection					Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		September 29, 1917	January 29, 1918	February 19, 1918	April 22, 1918	August 3, 1918			
				lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
50	None	None	None	7.2	4.5	0.3	5.9	5.7	23.6	....	....
51	Limestone	2000 lbs.	None	8.5	5.4	0.3	4.7	1.9	20.8	−2.8	....
52	Dolomite	2000 lbs.	None	8.5	4.5	0.7	3.5	2.5	19.7	−3.9	....
53	CaO	2000 lbs.	None	10.6	5.5	1.5	4.2	2.5	24.3	0.7	....
54	CaO	3750 lbs.	None	11.9	11.4	1.4	9.8	5.2	39.7	16.1	....
55	MgO	2000 lbs.	None	13.0	7.5	1.5	5.5	6.0	33.5	9.9	....
56	MgO	3750 lbs.	None	17.8	5.9	4.2	8.9	3.6	40.4	16.8	....
57	None	None	$FeSO_4$	4.3	2.0	0.6	1.9	4.2	13.0	−10.6	....
58	CaO	3750 lbs.	$FeSO_4$	7.6	4.5	1.8	4.4	3.2	21.5	−2.1	8.5
59	MgO	3750 lbs.	$FeSO_4$	7.5	5.8	2.3	4.5	2.8	22.9	−0.7	9.9
60	CaO	32 tons	$FeSO_4$	0	0.1	0	0.2	14.9	15.2	−8.4	2.2
61	MgO	32 tons	$FeSO_4$	4.6	6.0	0.6	3.0	12.2	26.4	2.8	13.4
62	None	None	Pyrite	8.2	1.5	0.7	3.9	3.5	17.8	−5.8	....
63	CaO	3750 lbs.	Pyrite	18.6	10.3	2.1	9.8	5.3	46.1	22.5	28.3
64	MgO	3750 lbs.	Pyrite	17.6	10.9	1.6	16.3	4.6	51.0	27.4	33.2
65	CaO	32 tons	Pyrite	0	0.2	0	0.4	23.3	23.9	0.6	6.1
66	MgO	32 tons	Pyrite	8.9	5.4	1.1	2.5	17.1	35.0	11.4	17.2
67	None	None	Sulfur	8.1	2.1	0.4	0.9	1.0	12.5	−11.1	....
68	CaO	3750 lbs.	Sulfur	8.3	3.4	0.8	7.5	2.3	22.3	−1.3	9.8
69	MgO	3750 lbs.	Sulfur	9.5	7.4	0	7.4	4.4	28.7	5.1	16.2
70	CaO	32 tons	Sulfur	0	0.2	1.1	1.1	17.1	19.5	−4.1	7.0
71	MgO	32 tons	Sulfur	5.9	3.5	...*	2.4	10.2	22.0	−1.6	9.5

* No leaching.

Rainfall for the annual period 37.69 inches.

initial intensity of treatment approaching that caused by the ferrous salt. The heavy burnt-lime addition shows the same result in this group as in the 2 preceding groups. All 4 basic treatments likewise show increases

over the loss from the group control, and the lime magnesia additions show much the same intra-relationships.

Second year. During the second year (table 2) all of the 6 no-sulfur tanks

TABLE 2

Periodic and total losses of nitrate nitrogen from a loam soil during the second year after treatments of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT PER 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1918 TO AUGUST 3, 1919							
	Calcic-magnesic		Equivalence of 1000 pounds of S	Date of collection					Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		December 11, 1918	January 3, 1919	February 24, 1919	April 22, 1919	August 4, 1919			
				lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
50	None	None	None	32.0	0.8	0.6	1.1	14.4	48.9	....	....
51	Limestone	2000 lbs.	None	42.3	1.5	1.4	1.7	16.5	63.4	14.5	....
52	Dolomite	2000 lbs.	None	36.7	1.5	1.4	1.9	12.7	54.2	5.3	....
53	CaO	2000 lbs.	None	36.0	2.0	1.4	1.2	17.9	58.5	9.6	....
54	CaO	3750 lbs.	None	48.6	2.9	1.9	2.2	16.6	72.2	23.3	....
55	MgO	2000 lbs.	None	33.5	2.0	1.5	1.1	17.4	55.5	6.6	....
56	MgO	3750 lbs.	None	38.8	5.5	1.8	2.2	17.4	65.7	16.8	....
57	None	None	$FeSO_4$	28.2	0.6	0.4	0.6	6.7	36.5	−12.4	....
58	CaO	3750 lbs.	$FeSO_4$	32.5	1.5	1.2	1.5	12.6	49.3	0.4	12.8
59	MgO	3750 lbs.	$FeSO_4$	23.1	7.5	1.4	1.6	11.9	45.5	−3.4	9.0
60	CaO	32 tons	$FeSO_4$	84.2	9.7	4.2	4.7	25.9	128.7	79.8	92.2
61	MgO	32 tons	$FeSO_4$	125.4	10.9	1.0	2.0	5.8	145.1	96.2	108.6
62	None	None	Pyrite	18.7	1.5	0.8	0.9	6.0	27.9	−21.0	....
63	CaO	3750 lbs.	Pyrite	38.4	2.0	1.4	1.9	11.0	54.7	5.8	26.8
64	MgO	3750 lbs.	Pyrite	40.8	2.3	1.5	2.6	13.9	61.1	12.2	33.2
65	CaO	32 tons	Pyrite	74.0	7.3	5.8	4.9	33.1	125.1	76.2	97.2
66	MgO	32 tons	Pyrite	80.2	14.6	0.4	2.5	8.0	105.7	56.8	77.8
67	None	None	Sulfur	19.4	1.6	0.8	1.3	10.5	33.6	−15.3	....
68	CaO	3750 lbs.	Sulfur	33.8	1.7	0.6	0.8	7.8	44.7	−4.2	11.1
69	MgO	3750 lbs.	Sulfur	32.6	1.9	1.6	2.3	13.4	51.8	2.9	18.2
70	CaO	32 tons	Sulfur	80.0	5.6	3.4	5.0	42.3	136.3	87.4	102.7
71	MgO	32 tons	Sulfur	122.5	8.9	0.8	2.1	7.0	141.3	92.4	107.7

Rainfall for the annual period 51.41 inches.

showed nitrate losses in excess of the outgo from the no-treatment control. Limestone proved more active than dolomite in causing nitrate outgo, while the 3750-pound applications of both CaO and MgO proved more accelerative than the corresponding 2000-pound additions. The largest fractions came

out in the leachings between August and December. The next largest came out during the period between the following April and August, while only small amounts were leached during the other 3 collection periods of winter

TABLE 3

Periodic and total losses of nitrate nitrogen from a loam soil during the third year after treatments of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT PER 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1919, TO AUGUST 3, 1920								
	Calcic-magnesic		Equivalence of 1000 pounds of S	Date of collection						Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		October 14, 1919	December 8, 1919	February 4, 1920	March 13, 1920	April 2, 1920	June 21, 1920			
				lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
50	None	None	None	5.7	0.4	1.6	1.2	0.7	4.9	14.5	....	....
51	Limestone	2000 lbs.	None	13.2	4.2	1.9	1.8	1.6	4.9	27.6	13.1	...
52	Dolomite	2000 lbs.	None	9.7	3.7	1.7	1.5	1.4	2.5	20.5	6.0	....
53	CaO	2000 lbs.	None	13.7	4.5	1.4	0.9	1.2	3.7	25.4	10.9	....
54	CaO	3750 lbs.	None	14.9	5.2	3.7	2.4	2.5	6.0	34.7	20.2	....
55	MgO	2000 lbs.	None	13.3	3.5	2.6	2.0	1.5	4.5	27.4	12.9	....
56	MgO	3750 lbs.	None	16.8	5.5	3.4	2.4	2.4	4.6	35.1	20.6	....
57	None	None	$FeSO_4$	11.1	0.8	0.8	0.8	0.5	1.5	15.5	1.0	....
58	CaO	3750 lbs.	$FeSO_4$	12.4	3.3	1.8	1.2	1.6	4.7	25.1	10.6	9.6
59	MgO	3750 lbs.	$FeSO_4$	11.6	5.2	3.5	2.0	2.0	5.3	29.6	15.1	14.1
60	CaO	32 tons	$FeSO_4$	47.1	37.7	8.9	4.0	4.8	8.8	111.3	96.8	95.8
61	MgO	32 tons	$FeSO_4$	37.5	17.2	3.8	2.5	3.4	5.2	69.6	55.1	54.1
62	None	None	Pyrite	9.0	1.9	1.8	0.7	1.2	2.3	16.9	2.4	....
63	CaO	3750 lbs.	Pyrite	9.1	4.9	1.9	1.9	1.9	6.2	25.9	11.4	9.0
64	MgO	3750 lbs.	Pyrite	10.7	5.8	2.9	1.6	1.6	4.6	27.2	12.7	10.3
65	CaO	32 tons	Pyrite	41.4	29.6	8.0	4.4	4.8	19.6	107.8	93.3	90.9
66	MgO	32 tons	Pyrite	19.6	11.4	3.5	2.3	2.7	6.5	46.0	31.5	29.1
67	None	None	Sulfur	8.1	2.7	1.1	0.7	0.6	2.4	15.6	1.1	....
68	CaO	3750 lbs.	Sulfur	9.6	4.8	2.5	1.5	1.1	4.4	23.9	9.4	8.3
69	MgO	3750 lbs.	Sulfur	7.4	4.7	2.6	1.5	1.7	3.2	21.1	6.6	5.5
70	CaO	32 tons	Sulfur	24.4	21.7	5.9	3.4	3.8	16.3	75.5	61.0	59.9
71	MgO	32 tons	Sulfur	22.0	12.8	3.0	2.3	2.7	6.5	49.3	34.8	33.7

Rainfall for annual period 54.75 inches.

and early spring. This same relationship holds for the other 3 series of 5 tanks each.

In the $FeSO_4$ group the unsupplemented sulfate addition still proved depressive to nitrate outgo. The 2 light lime and magnesia treatments again

failed to overcome the influence of the added sulfate. The reverse is true for the heavy rate, however, both showing large increases above both the untreated and the group controls.

TABLE 4

Periodic and total losses of nitrate nitrogen from a loam soil during the fourth year after treatments of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT FOR 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1910, TO AUGUST 3, 1921									
	Calcic-magnesic		Equivalence of 1000 pounds of S	Date of collection							Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		August 14, 1920	September 10, 1920	December 8, 1920	January 10, 1921	February 10, 1921	April 23, 1921	August 4, 1921			
				lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
50	None	None	None	7.4	2.8	1.0	0.3	0.4	1.1	9.7	22.7	...	...
51	Limestone	2000 lbs.	None	8.8	3.1	4.2	0.6	0.6	1.7	14.4	33.4	10.7	...
52	Dolomite	2000 lbs.	None	8.6	3.3	2.3	0.4	0.6	0.7	12.2	28.1	5.4	...
53	CaO	2000 lbs.	None	6.8	3.2	3.4	0.4	0.6	1.1	13.1	28.6	5.9	....
54	CaO	3750 lbs.	None	6.9	2.5	1.3	0.3	0.5	2.0	5.9	19.4	−3.3	....
55	MgO	2000 lbs.	None	5.6	2.3	3.0	0.9	0.8	1.2	11.0	24.8	2.1	....
56	MgO	3750 lbs.	None	7.9	4.5	4.7	1.3	1.0	2.2	17.5	39.1	16.4	....
57	None	None	$FeSO_4$	4.9	0.8	0.5	0.3	0.4	0.8	9.5	17.2	−5.5	....
58	CaO	3750 lbs.	$FeSO_4$	4.8	2.5	2.2	0.4	0.8	2.0	10.5	23.2	0.5	6.0
59	MgO	3750 lbs.	$FeSO_4$	8.7	2.1	2.8	0.7	1.0	2.3	10.0	27.6	4.9	10.4
60	CaO	32 tons	$FeSO_4$	36.0	11.5	6.1	...*	1.5	4.0	...*	59.1	36.4	41.9
61	MgO	32 tons	$FeSO_4$	16.5	3.6	4.9	0.5	0.6	1.2	8.0	35.3	12.6	18.1
62	None	None	Pyrite	6.1	1.8	1.3	0.5	0.1	0.9	8.7	19.4	−3.3	....
63	CaO	3750 lbs.	Pyrite	10.1	2.7	4.0	0.5	0.4	1.7	8.4	27.8	5.1	8.4
64	MgO	3750 lbs.	Pyrite	8.4	4.7	3.0	0.7	0.8	1.6	10.4	29.6	6.9	10.2
65	CaO	32 tons	Pyrite	34.3	12.6	17.2	3.4	2.7	5.5	22.8	98.5	75.8	79.1
66	MgO	32 tons	Pyrite	15.9	3.1	4.3	0.5	0.6	1.2	6.5	32.1	9 4	12.7
67	None	None	Sulfur	8.2	1.2	1.2	0.4	0.3	0.6	8.1	20.0	−2.7	....
68	CaO	3750 lbs.	Sulfur	12.5	1.6	2.1	0.3	0.5	0.9	8.7	26.6	3.9	6.6
69	MgO	3750 lbs.	Sulfur	13.4	2.7	1.6	0.5	0.5	1.2	7.6	27.5	4.8	7.5
70	CaO	32 tons	Sulfur	38.3	12.4	16.2	4.1	3.3	6.1	22.5	102.9	80.2	82.9
71	MgO	32 tons	Sulfur	22.0	3.6	4.7	0.6	0.5	1.7	7.2	40.3	17.6	20.3

* No leaching. Rainfall for annual period 55.19 inches.

In principle, the same holds true also for the other 2 groups. Since much less of the 3750-pound additions was required to neutralize the smaller amounts of sulfuric acid, or acid salts, generated in the pyrite group, there were larger residues from the earthy additions in the pyrite tanks. This probably ac-

counts for the larger outgo of nitrates from the lighter treatments in these tanks.

Third year. In the third year (table 3) the limestone treatment was still more active than the dolomite, while the 3750-pound CaO and MgO additions

TABLE 5

Periodic and total losses of nitrate nitrogen from a loam soil during the fifth year after treatment of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT PER 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1921 TO AUGUST 3, 1922							
	Calcic-magnesic		Equivalence of 1000 pounds of S	Date of collection					Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		December 20, 1921	January 21, 1922	March 2, 1922	April 28, 1922	August 3, 1922			
				lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
50	None	None	None	14.3	0.8	1.1	1.3	2.9	20.4	....	....
51	Limestone	2000 lbs.	None	8.7	0.5	1.2	1.1	2.0	13.5	−6.9	....
52	Dolomite	2000 lbs.	None	9.9	0.6	1.0	1.0	1.6	14.1	−6.3	....
53	CaO	2000 lbs.	None	9.2	0.7	1.1	2.2	1.9	15.1	−5.3	....
54	CaO	3750 lbs.	None	9.0	0.8	1.3	1.6	3.6	16.3	−4.1	....
55	MgO	2000 lbs.	None	9.5	0.9	1.1	2.2	4.7	18.4	−2.0	....
56	MgO	3750 lbs.	None	9.5	1.1	1.1	2.0	2.9	16.6	−3.8	....
57	None	None	$FeSO_4$	6.5	1.1	0.8	1.6	2.2	12.2	8.2	....
58	CaO	2750 lbs.	$FeSO_4$	10.2	1.4	1.1	1.7	4.6	19.0	1.4	6.8
59	MgO	3750 lbs.	$FeSO_4$	13.6	1.6	1.3	1.2	4.1	21.8	1.4	9.6
60	CaO	32 tons	$FeSO_4$	21.9	5.0	2.0	0.8	2.4	32.1	11.7	19.9
61	MgO	32 tons	$FeSO_4$	18.1	3.2	1.1	1.2	1.7	25.3	4.9	13.1
62	None	None	Pyrite	16.6	0.8	1.2	2.1	3.4	24.1	3.7	....
63	CaO	3750 lbs.	Pyrite	9.5	1.0	1.0	1.6	2.1	15.2	−5.2	8.9
64	MgO	3750 lbs.	Pyrite	9.9	1.4	1.3	1.6	4.3	18.5	−1.9	5.6
65	CaO	32 tons	Pyrite	33.4	4.3	2.2	2.7	6.5	49.1	28.7	25.0
66	MgO	32 tons	Pyrite	15.7	3.0	1.1	1.7	2.6	24.1	3.7	0
67	None	None	Sulfur	11.0	0.5	0.5	1.4	3.0	16.4	−4.0	....
68	CaO	3750 lbs.	Sulfur	11.1	0.7	0.6	0.8	3.2	16.4	−4.0	0
69	MgO	3750 lbs.	Sulfur	10.3	1.0	0.7	1.3	4.8	18.1	−2.3	1.7
70	CaO	32 tons	Sulfur	33.1	3.2	2.5	2.6	8.0	49.4	29.0	33.0
71	MgO	32 tons	Sulfur	19.6	2.6	1.0	1.0	1.8	26.0	5.6	9.6

Rainfall for the annual period 56.75 inches.

again caused nitrate leachings greater than those from the 2000-pound treatments.

In all 3 of the sulfur-material controls, the losses of nitrates for the year

were about equal to the loss from the untreated tank. Increased nitrate leachings came from all of the 12 lime and magnesia tanks of the 3 sulfur-addition series. The 3 pairs of 32-ton CaO and MgO additions caused the

TABLE 6

Periodic and total losses of nitrate nitrogen from a loam soil during the sixth year after treatments of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT PER 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1922, TO AUGUST 3, 1923							
	Calcic-magnesic		Equivalence of 1000 pounds of S	Date of collection					Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		December 17, 1922	January 27, 1923	February 13, 1923	March 19, 1923	July 28, 1923			
				lbs.	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*	*lbs.*
50	None	None	None	9.3	0.9	0.9	1.3	4.2	16.6	....	....
51	Limestone	2000 lbs.	None	5.8	1.3	1.1	1.2	3.5	12.9	−3.7	....
52	Dolomite	2000 lbs.	None	4.5	0.8	0.8	0.7	2.4	9.2	−7.4	....
53	CaO	2000 lbs.	None	11.0	1.5	1.1	1.3	4.0	18.9	2.3	....
54	CaO	3750 lbs.	None	8.1	1.3	1.1	1.5	4.7	16.7	0.1	....
55	MgO	2000 lbs.	None	11.7	1.3	1.1	1.4	4.3	19.8	3.2	....
56	MgO	3750 lbs.	None	9.4	1.5	1.1	1.1	2.9	16.0	−0.6	....
57	None	None	$FeSO_4$	6.8	0.6	0.5	0.4	1.5	9.8	−6.8	....
58	CaO	3750 lbs.	$FeSO_4$	5.7	1.4	1.0	1.4	4.0	13.5	−3.1	3.7
59	MgO	3750 lbs.	$FeSO_4$	15.1	1.7	1.1	1.2	3.3	22.4	−5.8	12.6
60	CaO	32 tons	$FeSO_4$	13.5	2.0	0.8	0.7	1.3	18.3	1.7	8.5
61	MgO	32 tons	$FeSO_4$	23.1	1.5	1.1	0.8	0.6	27.1	10.5	18.6
62	None	None	Pyrite	15.9	0.8	0.6	0.5	1.4	19.2	2.6	....
63	CaO	3750 lbs.	Pyrite	18.6	1.0	1.0	0.9	2.6	24.1	7.5	4.9
64	MgO	3750 lbs.	Pyrite	14.3	1.4	1.0	0.8	3.5	21.0	4.4	1.8
65	CaO	32 tons	Pyrite	21.6	1.4	1.1	1.2	1.7	27.0	10.4	7.8
66	MgO	32 tons	Pyrite	37.9	2.2	1.8	1.3	0.8	44.0	27.4	24.8
67	None	None	Sulfur	14.0	0.7	0.4	0.3	1.4	16.8	0.2	....
68	CaO	3750 lbs.	Sulfur	10.5	0.7	0.5	0.5	3.3	15.5	−1.1	−1.3
69	MgO	3750 lbs.	Sulfur	13.6	0.9	0.6	0.4	2.9	18.4	−1.8	1.6
70	CaO	32 tons	Sulfur	29.7	1.4	1.0	1.1	1.6	34.8	18.2	18.0
71	MgO	32 tons	Sulfur	32.8	1.7	1.2	1.0	0.7	37.4	20.8	20.6

Rainfall for the annual period 55.03 inches.

leaching of much larger quantities of nitrates than those which came from the corresponding additions at the 3750-pound rate.

Fourth year. During the fourth year (table 4) 5 of the 6 unsupplemented alkali-earth treatments caused increases in nitrate outgo. The one exception,

CaO at the 3750-pound rate, resulted in depressed outgo, but the corresponding MgO treatment gave the largest increase of the series. Limestone again proved more active than dolomite upon the outgo of nitrates.

All 3 sulfur materials still showed depressive effects when unsupplemented, while all 12 supplements served to eliminate the repressive effect of the sulfur materials, the heavier treatments again proving more effective in this regard. The 32-ton lime treatment in each case proved more accelerative than its MgO parallel upon outgo of nitrates.

Fifth year. During the fifth year (table 5) all of the 6 unsupplemented calcic and magnesic treatments caused nitrate losses smaller than the outgo from the control. The differences were due to the disparities in the first collection period. During the other 4 periods the several treatments were in close agreement among themselves and with the control.

In the remaining 15 tanks the most consistent showing was that of the augmentative effect of the heavy burnt lime. Here again the differences were due mainly to the greater leachings during the initial collection period of the year.

Sixth year. During the sixth year (table 6) the control suffered a smaller loss than the limestone and dolomite treatments and practically the same as the outgo from each of the 3750-pound additions. During this year the differences between nitrate losses were not very extensive; but both of the 2000-pound oxide treatments caused greater leaching than those which came from the 3750-pound treatments.

In the 3 sulfur-supplement groups, the variations of controls and light additions of CaO and MgO from the no-treatment control were not nearly so marked as were those induced by the 32-ton treatments. These latter variations were largely due again to the long, dry, late summer and fall period. The one exception to marked increase caused by heavy CaO, that of the heavy lime plus $FeSO_4$, may be influenced by the amount of sulfate still unleached (7).

SUMMARY OF FULL 6-YEAR PERIOD

The total losses for the 6-year period are given in table 7 and in figure 1. The dolomite treatment resulted in no loss of nitrogen in excess of that from the control. The effects produced by chemically equivalent amounts of burnt lime and 100-mesh limestone were practically identical, while the equivalent MgO treatment caused a loss of only 8.2 pounds more than the average of the losses from the lime and limestone additions. Increases in rate from 2000 pounds to 3750 pounds caused 117 per cent and 102 per cent increases in losses in excess of the control for CaO and MgO, respectively. The burnt lime, limestone, and MgO equivalences caused losses of 16.1 per cent, 16.7 per cent, and 22.3 per cent, respectively, in excess of the total amount leached from the control. Corresponding increases of 35.6 per cent and 45.1 per cent were caused by CaO and MgO, respectively, at the 3750-pound rate.

All 3 of the unsupplemented sulfur materials caused a distinct depression in the outgo of nitrates and presumably this would mean a corresponding depression in nitrification. The maximum depression was manifested by the

TABLE 7

Total losses of nitrate nitrogen from a loam soil during a 6-year period after treatments of calcic and magnesic materials, with and without sulfur additions

TANK NUMBER	TREATMENT FOR 2,000,000 POUNDS OF SOIL			NITRATE N LEACHED PER 2,000,000 POUNDS OF SOIL FROM AUGUST 3, 1917, TO AUGUST 3, 1923								
	Calcic-magnesic		Equivalence of 1000 pounds of S	Annual losses						Total	Excess above loss from untreated soil	Excess above loss from group control
	Material	CaO equivalence		First	Second	Third	Fourth	Fifth	Sixth			
				lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
50	None	None	None	23.6	48.9	14.5	22.7	20.4	16.6	146.7	....	.....
51	Limestone	2000 lbs.	None	20.8	63.4	27.6	33.4	13.5	12.9	171.6	24.9	.....
52	Dolomite	2000 lbs.	None	19.7	54.2	20.5	28.1	14.1	9.2	145.8	−0.9	.....
53	CaO	2000 lbs.	None	24.3	58.5	25.4	28.6	15.1	18.9	170.8	24.1	.....
54	CaO	3750 lbs.	None	39.7	72.2	34.7	19.4	16.3	16.7	199.0	52.3	.....
55	MgO	2000 lbs.	None	33.5	55.5	27.4	24.8	18.4	19.8	179.4	32.7	.....
56	MgO	3750 lbs.	None	40.4	65.7	35.1	39.1	16.6	16.0	212.9	66.2	.....
57	None	None	$FeSO_4$	13.0	36.5	15.5	17.2	12.2	9.8	104.2	−42.5	....
58	CaO	3750 lbs.	$FeSO_4$	21.5	49.3	25.1	23.2	19.0	13.5	151.6	4.9	47.4
59	MgO	3750 lbs.	$FeSO_4$	22.9	45.5	29.6	27.6	21.8	22.4	169.8	23.1	65.6
60	CaO	32 tons	$FeSO_4$	15.2	128.7	111.3	59.1	32.1	18.3	364.7	218.0	260.5
61	MgO	32 tons	$FeSO_4$	26.4	145.1	69.6	35.3	25.3	27.1	328.8	182.1	224.6
62	None	None	Pyrite	17.8	27.9	16.9	19.4	24.1	19.2	125.3	−21.4	....
63	CaO	3750 lbs.	Pyrite	46.1	54.7	25.9	27.8	15.2	24.1	193.8	47.1	68.5
64	MgO	3750 lbs.	Pyrite	51.0	61.1	27.2	29.6	18.5	21.0	208.4	61.7	83.1
65	CaO	32 tons	Pyrite	23.9	125.1	107.8	98.5	49.1	27.0	431.4	284.7	306.1
66	MgO	32 tons	Pyrite	35.0	105.7	46.0	32.1	24.1	44.0	286.9	140.2	161.6
67	None	None	Sulfur	12.5	33.6	15.6	20.0	16.4	16.8	114.9	−31.8	....
68	CaO	3750 lbs.	Sulfur	22.3	44.7	23.9	26.6	16.4	15.5	149.4	2.7	34.5
69	MgO	3750 lbs.	Sulfur	28.7	51.8	21.1	27.5	18.1	18.4	165.6	18.9	50.7
70	CaO	32 tons	Sulfur	19.5	136.3	75.5	102.9	49.4	34.8	418.4	271.7	303.5
71	MgO	32 tons	Sulfur	22.0	141.3	49.3	40.3	26.0	37.4	316.3	169.6	201.4

Rainfall for the 6-year period 310.82 inches.

soluble acid salt of iron. The rapidly oxidized sulfur control showed next in depressive effect, while the more slowly oxidized pyrite exhibited the least depression of the 3 controls.

The light supplements of lime and magnesia served to completely counteract

this effect for all 3 sulfur treatments. In the case of pyrite the reversal was so great for both lime and magnesia as to give almost the same respective losses which were caused by the 3750-pound additions without sulfur. In the other 2 groups, however, the antagonistic effects of lime and magnesia upon the

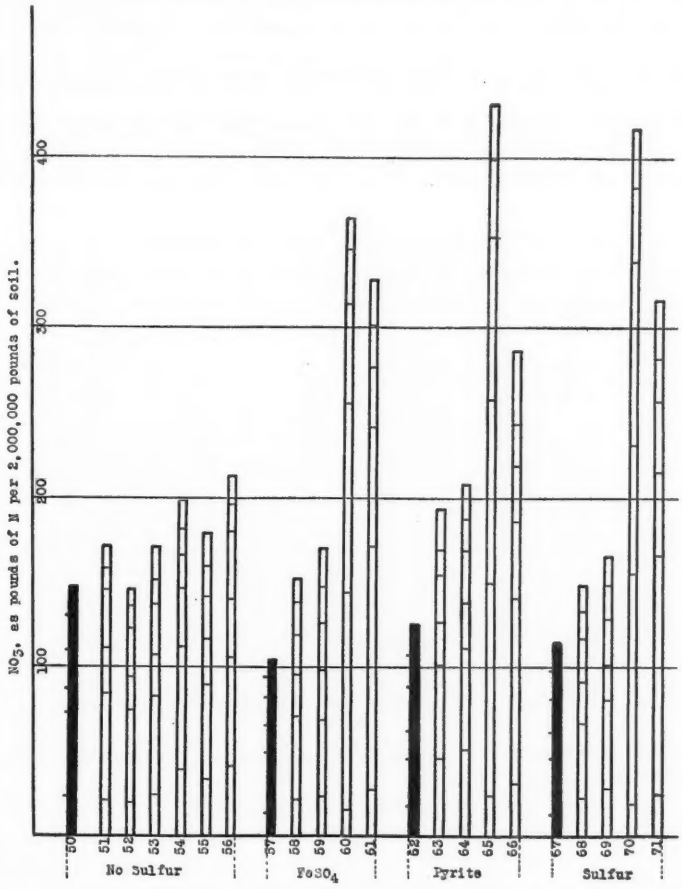

FIG. 1. TOTAL LOSSES OF NITRATE N FROM A LOAM SOIL DURING A 6-YEAR PERIOD AFTER TREATMENTS OF CALCIC AND MAGNESIC MATERIALS, WITH AND WITHOUT SULFUR ADDITIONS.

$FeSO_4$ and sulfur failed to produce nitrate leachings equal to those which came from the unsupplemented lime and magnesia at the 2000-pound rate. In each group the 32-ton lime treatment produced the heaviest outgo of nitrates. Next in order came the heavy magnesia. In each instance the

effect of the heavy addition was greatly in excess of the corresponding light treatment for both lime and magnesia.

In intra-group comparisons, two consistent relationships stand out. In each instance the light MgO treatment has proved distinctly more accelerative than CaO upon the outgo of nitrates. With the heavier treatments the reverse is true.

THE INFLUENCE OF HEAVY CaO TREATMENTS UPON INITIAL NITRATE OUTGO

By reference to table 1 it will be observed that the 32-ton additions of CaO practically inhibited the leaching of nitrates during the period from August to the following April of the first year. This was true irrespective

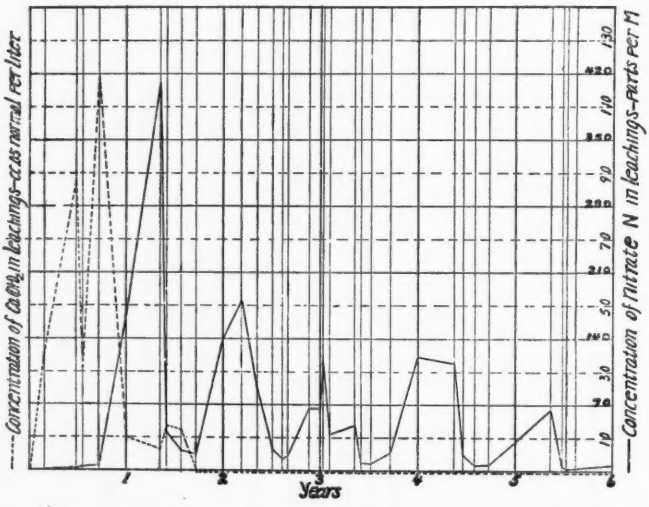

FIG. 2. RELATION BETWEEN $Ca(OH)_2$ CONCENTRATION AND NITRATE OCCURRENCE IN LEACHINGS FROM HEAVILY LIMED SOIL

of the form in which sulfur supplements were applied. After that time nitrates began to come through in copious amounts. In parallel unpublished work with the same type of soil, this was found also with both 32-ton and 100-ton additions. Determinations of nitrates and $Ca(OH)_2$ were made upon each separate collection of leachings. This parallel is shown in the graph, figure 2. The peaks of the $Ca(OH)_2$ curves correspond to the minima of the nitrate occurrences. This finding coincides with that of Hutchinson (2) as to the partial sterilization effected by hydrated lime. It is also apparent, that, with the disappearance of $Ca(OH)_2$, as a result of absorption and carbonation, renewal and greatly increased nitrification ensued.

EXTRACTABILITY OF NITRATES IN PRESENCE OF EXCESS OF $Ca(OH)_2$

The paucity of nitrates in the leachings during the persistence of $Ca(OH)_2$ in the soil of the tanks did not necessarily prove that the soil was devoid of nitrates. It might be assumed that the excess of lime had fixed nitrates in a manner similar to that responsible for sulfate fixation (7, 8) by the same treatment. This point was studied by means of a comparison between the air-dry soil after 6 years storage and the same soil as obtained in the moist condition fresh from the field. Soil suspensions alone and nitrate-fortified, both with and without excesses of lime, were made in ratio of 500 gm. of soil and 2500 cc. of water. Five minutes' agitation was given initially with one daily subsequent agitation including the 1-week period, after which the

TABLE 8

Effect of an excess of $Ca(OH)_2$ upon 1–5 aqueous extraction of nitrates from a dried laboratory soil and the same soil fresh from the field, with and without additions of $Ca(NO_3)_2$†*

TREATMENT	NITRATES AS PARTS PER MILLION OF SOLUTION EXTRACTED AFTER					
	30 minutes	24 hours	48 hours	1 week	8 months	Average
Laboratory soil maintained air-dry for 6 years						
None	304	220	280	228	205	247
$Ca(OH)_2$	260	176	265	260	...	240
$Ca(NO_3)_2$	284	284	300	284	265	283
$Ca(NO_3)_2+Ca(OH)_2$	224	228	305	252	245	251
Same soil moist and freshly taken						
None	7.0	4.4	6.6	4.8	1.1	4.8
$Ca(OH)_2$	7.5	7.0	7.4	7.5	6.3	7.1
$Ca(NO_3)_2$	32.4	31.6	30.4	30.0	1.8	24.9
$Ca(NO_3)_2+Ca(OH)_2$	31.6	31.2	29.6	32.4	29.6	30.9

* 16 gm. CaO.

† 24.6 p.p.m. of solution.

suspensions were left untouched for 8 months. Between the 1-week and 8-month intervals algae appeared in all of the no-lime combinations, but they were absent in the lime admixtures. The periodic recoveries are given in table 8.

From the data of table 8, it is apparent that the dried laboratory soil was either (*a*) very high in nitrate content at the time of sampling, or (*b*) nitrates accumulated during drying and storing, or both, or (*c*) contamination occurred. The periodic data vary as to repressive effect of lime upon the outgo of soil nitrates and added nitrates, but they do show that very large quantities of nitrates were leached where the excess of lime was present. However, the moist soil furnished the desired data, since the moist condition prevailed

initially and during the period of leaching. The nitrate recoveries from the unfortified moist soil were greater in every case where lime was added. When fortified with $Ca(NO_3)_2$ the soil plus lime suspensions gave nitrate yields approximately equivalent to or greater than those from the moist no-lime soil fortified with $Ca(NO_3)_2$. The low result for the no-lime fortified soil after 8 months was from a suspension containing a heavy growth of algae and considerable gas, and may be attributed to the joint effect of algae and denitrification. It thus appears that the heavy lime treatments were responsible for a paucity of nitrates in the lysimeters and that this paucity was correctly indicated by the meagreness of nitrates in the initial leachings.

SUMMARY

Data on nitrate outgo covering a 6-year period are given for 22 embedded tanks containing different calcic and magnesic treatments at different rates, with and without supplements of one of 3 forms of sulfur.

Periodic, annual and total leachings are tabulated, discussed and graphed.

Two thousand pounds of CaO as burnt-lime and 100-mesh limestone gave almost identical total results, while dolomite showed no increase. Increase in rate from 2000 pounds to 3750 pounds gave augmented nitrate outgo for both CaO and MgO.

Unsupplemented additions of $FeSO_4$, pyrite and elementary sulfur caused depressed outgo of nitrates.

Supplements of both CaO and MgO, at the 3750-pound rate, overcame the depressive effects for the 3 sulfur materials, MgO having proved more effective than CaO.

Supplements of CaO at the 32-ton rate caused a much greater total outgo of nitrates than was induced by equivalent additions of MgO to each of the 3 sulfur materials.

The 32-ton CaO treatments were initially decidedly inhibitive to nitrate outgo; the corresponding MgO additions were not.

Partial sterilization and subsequent activation are shown by graphs correlating $Ca(OH)_2$ titrations and NO_3 determinations.

Laboratory studies of the same soil, moist and after storage, and with and without $Ca(NO_3)_2$ fortification showed that the small initial outgo of nitrates from heavy liming was due to paucity of nitrate supply, rather than depressed nitrate solubility.

REFERENCES

(1) ALLEN, E. R., AND BONAZZI, A. 1915 On nitrification. *In* Ohio Agr. Exp. Sta. Tech. Bul. 7, p. 37.

(2) HUTCHINSON, H. B. 1913 The partial sterilization of the soil by means of caustic lime. *In* Jour. Agr. Sci., v. 5, p. 320–331.

(3) LYON, T. L., AND BIZZELL, J. A. 1918 Lysimeter experiments. *In* N. Y. (Cornell) Agr. Exp. Sta. Mem. 2, p. 38.

(4) LYON, T. L., AND BIZZELL, J. A. 1921 Lysimeter experiments II. *In* N. Y. (Cornell) Agr. Exp. Sta. Mem. 41, p. 62.

(5) MACINTIRE, W. H. 1919 The carbonation of burnt lime in soils. *In* Soil Sci., v. 7, p. 494.

(6) MACINTIRE, W. H. 1919 The liberation of native soil potassium induced by different calcic and magnesic materials, as measured by lysimeter leachings. *In* Soil Sci., v. 8, p. 395.

(7) MACINTIRE, W. H., SHAW, W. M., AND YOUNG, J. B. 1923 Influence of calcic and magnesic treatments upon sulfate leachings from soil alone and with additions of ferrous sulfate, pyrite, and sulfur. *In* Soil Sci., v. 16, p. 159–161.

(8) MACINTIRE, W. H., AND SHAW, W. M. 1924 The effect of soil suspensions upon the solubility of the sulfate radical in the system $Ca(OH)_2-CaSO_4-H_2O$. *In* Soil Sci., v. 17, p. 65–89.

(9) MOOERS, C. A., AND MACINTIRE, W. H. 1921 The comparative effects of various forms of lime on the nitrogen content of the soil. *In* Jour. Am. Soc. Agron., v. 13, no. 5, p. 185.

(10) STEVENS, F. L., AND WITHERS, W. A. 1909 Studies in soil bacteriology. III. Concerning methods for determination of nitrifying and ammonifying powers. *In* Centbl. Bakt., Parasit und Infektion, Abt. 2, v. 25, p. 75.

(11) TUNG, SHIH TSIN 1923 Absorption of nitrate by soil and insoluble powder. Master's Thesis, Cornell Univ., unpublished.

THE IRON, CHLORINE, AND SULFUR CONTENTS OF GRAINS AND THE INFLUENCE OF IRRIGATION WATER UPON THEM

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A search of the literature upon the subject reveals the fact that very little accurate information is available on the content of iron, chlorine and sulfur in grains. This is due primarily to the faulty methods used in analysis. Moreover, it has been found that the total ash, calcium, magnesium, potassium, and phosphorus content of wheat, oats and barley is a function of the irrigation water applied to the soil during the production of the grains (5). Therefore, these results are offered for two reasons: (*a*) because they give accurate averages of the quantity of iron, chlorine, and sulfur contained in wheat, oats, and barley grown under known conditions and (*b*) because they show the influence of irrigation water upon the quantity of these elements taken up by wheat, oats, and barley and stored within the grain.

The grain was grown on the Greenville Experiment Farm, the soil of which is a very productive calcareous loam of sedimentary origin. The surface foot contains 2.12 per cent of acid-soluble iron and only 0.0068 per cent of total sulfur. The complete analysis of the soil is given elsewhere (7).

The analyses of the grain were all made in duplicate on composite samples composed of from three to five yearly yields and reported on the dry basis of the grains. The results as reported in each table are averages of from six to ten separate analyses made on grain grown on from three to five plats receiving like quantities of irrigation water. The yield of grain and treatment are those given by Harris (9) and Harris and Pittman (10, 11). The ash, phosphorus, calcium, magnesium, and potassium content of these same grains has been previously reported (1).

The iron was determined by the colorimetric method of Berman (2) after the ash had been prepared by the official methods (15) and the chlorine was determined by the regular official method.

The sulfur was determined by fusing it with sodium peroxide and sodium carbonate and then precipitating and weighing it as barium sulfate (15).

The total iron content of the grain grown with varying quantities of irrigation water is given in table 1.

The iron content of the wheat increases progressively with the irrigation water applied, so that the wheat receiving 35 inches of irrigation water carries 68 per cent more iron than does the unirrigated wheat. The irrigated oats

and barley contain the same amounts of iron as do the non-irrigated grains. It would be valuable to know if the percentage in the total plant increases with the water applied. This would probably be true when the non-irrigated soil does not contain sufficient available iron for the production of a plant with its required amount of iron. Under this condition the irrigation water would increase the bacterial activities (4) which would render available more iron for the growing plant, for the quantity of iron found in the plant is a function of the supply available in the soil (19). Probably this relationship between microflora and available iron within the soil is a contributing factor in chlorosis. If this be true any factors which would increase bacterial activities, especially the acid producers, should tend to combat chlorosis.

TABLE 1

Iron found in 100 grams of wheat, oats, and barley grown with varying quantities of irrigation water

TREATMENT	IRON IN 100 GRAMS OF		
	Wheat	Oats	Barley
	mgm.	*mgm.*	*mgm.*
No irrigation water	19	21	28
15 inches irrigation water	25	21	27
35 inches irrigation water	32	18	26

TABLE 2

Chlorine found in 100 grams of grain grown with different quantities of irrigation water

TREATMENT	CHLORINE IN 100 GRAMS OF		
	Wheat	Oats	Barley
	mgm.	*mgm.*	*mgm.*
No irrigation water	33	111	129
15 inches irrigation water	75	99	153
35 inches irrigation water	89	100	88

In iron content the barley averages highest, the wheat second, and the oats lowest. The iron content of these grains is from four to six times that reported by Sherman (20) and of the barley is 33 per cent higher than the values reported by Petit (7). The greater quantity found in these grains is undoubtedly due to two factors: (*a*) the high iron content of the soil and (*b*) the active microflora of the soil (8). The high lime content of these soils would tend to keep the soluble iron very low were it not for an active microflora (14). Moreover, it is quite likely that in the absence of optimum moisture, temperature, or organic content the bacterial flora may be so influenced as to result in chlorosis.

Only 100 gm. of either of these grains would be required to meet Sherman's estimate (20) of man's daily iron requirement of 15 mgm. However, if the

milled flour contains only one-fifth of the total iron (20) the requirements would be correspondingly greater.

The chlorine content of these same grains is given in table 2.

The chlorine content of the wheat increases as the irrigation water applied increases. In the case of the barley and oats there is no relationship between the quantity of water applied and the clorine content. There is, however, a relationship between the time of application and the quantity applied and the chlorine content.

The sulfur content of these same grains is given in table 3.

The sulfur content of the wheat increases progressively with the increase of irrigation water, whereas in the case of the oats and barley there is an

TABLE 3

Sulfur found in 100 grams of wheat, oats, and barley grown with varying quantities of irrigation water

TREATMENT	SULFUR IN 100 GRAMS OF		
	Wheat	Oats	Barley
	mgm.	*mgm.*	*mgm.*
No irrigation water	144	238	152
5 inches irrigation water		219	156
10 inches irrigation water		205	132
15 inches irrigation water	197	201	126
20 inches irrigation water		221	113
35 inches irrigation water	213	183	115
52.5 inches irrigation water		191	131

TABLE 4

Indicated durability of Greenville Experiment Farm soil for production of wheat, oats, and barley

	50-BUSHEL CROP WHEAT	100-BUSHEL CROP OATS	75-BUSHEL CROP BARLEY
Nitrogen	52	39	41
Phosphorus	241	251	183
Sulfur	39	31	38

irregular decrease. This may be due to the hull in the case of the oats and barley but cannot be decided from these results.

The unirrigated wheat is lower, and the irrigated higher, in sulfur than either the oats or barley.

The sulfur content of the grains in many of the older analyses was made on the dry-ashed sample, a considerable loss thus being incurred. This has not occurred in our work, yet our results are lower than those reported by many workers (17, 20). This is undoubtedly due to the extremely low sulfur content of these soils. Viewed in the light of these results it is quite likely that the productivity of these soils would be materially increased by the application of sulfur-carrying fertilizers. Moreover, it is likely that part

of the increase in the ammonifying, nitrifying (3) and nitrogen-fixing powers (6) of these soils noted when sulfur-carrying salts are applied to this soil is due to the direct utilization of the sulfur by the microflora and only partly due to an increased solubility of other plant essentials rendered available by the resulting sulfuric acid.

The durability of this soil, measured in terms of its nitrogen, phosphorus, and sulfur content is given in table 4.

The above calculations are made for a 50-bushel crop of wheat, a 100-bushel crop of oats, and a 75-bushel crop of barley grain only, the highest nitrogen, phosphorus (5), and sulfur results obtained in these analyses being used. The soil contains in each acre-foot (3,600,000 pounds), the following: 3758 pounds of total nitrogen, 3312 pounds of total phosphorus, and 247 pounds of total sulfur. It is quite evident from these results that unless rain and snow are adding yearly the quantity required by the growing crop, sulfur is one of the limiting elements in crop production in this soil. From these results

TABLE 5

Ratio of sulfur to nitrogen in grain grown with varying quantities of irrigation water

TREATMENT	1 PART SULFUR TO THE FOLLOWING OF NITROGEN IN		
	Wheat	Oats	Barley
No irrigation water	16.6	11.6	13.5
5 inches irrigation water		11.3	13.0
10 inches irrigation water		11.9	15.7
15 inches irrigation water	10.2	11.6	14.4
20 inches irrigation water		10.4	15.9
35 inches irrigation water	9.5	11.7	
45 inches irrigation water		10.3	
52.5 inches irrigation water			15.4

and those reported earlier, on the influence of sulfur on the microflora of the soil, it is quite certain that the productivity of this soil would be increased materially by the use of a sulfur fertilizer.

The ratio of the nitrogen to the sulfur in these various grains is given in table 5.

The non-irrigated wheat carries the sulfur and nitrogen in very nearly the ratio in which they are found to occur in the vegetable proteins (16). This ratio decreases as the quantity of irrigation water applied to the growing crop increases. It is permissible to consider from the nearness borne to the ratio found in native vegetable proteins, that if the unirrigated wheat contains all its sulfur in the unoxidized form then the irrigated contains only 58 per cent of it in the oxidized form. The oats have a nearly constant sulfur-nitrogen ratio, and judged from the same viewpoint as the wheat, they contain 67 per cent of their sulfur in the unoxidized form. The barley carries a smaller percentage of oxidized sulfur than either the wheat or oats. It is certain,

therefore, either that there are non-sulfur-nitrogen-carrying compounds within the grain or else that the quantity of oxidized sulfur in grains is considerably higher than reported by Peterson (17).

The analysis of a considerable number of samples of wheat, oats, and barley grown over a number of years and with varying quantities of irrigation water reveals the fact that the iron content of wheat increased with the quantity of water applied during the growing season. The wheat grown with 35 inches of irrigation water contained 1.69 times as much iron as did that grown without water. The irrigation water was without effect on the iron content of oats and barley.

The chlorine content of wheat varied directly with the irrigation water applied during the growing season. That grown with 35 inches of irrigation water contained 2.7 times as much as that grown without irrigation water. No regularity was found in the case of the oats and barley.

The sulfur content of wheat increased as the quantity of irrigation water applied increased. A study of the sulfur-nitrogen ratio indicated that the increase was mainly oxidized sulfur. These results indicate that grains may carry considerable quantities of oxidized sulfur.

REFERENCES

(1) BALLAND, A. 1907 The distribution of sulfur in foods. *In* Jour. Pharm. et Chim., v. 6, s. 25, no. 2, p. 49–51. *Abs. in* Exp. Sta. Rec., v. 19, p. 59.

(2) BERMAN, LEWIS 1918 A rapid method for the determination of iron in small quantities of blood. *In* Jour. Biol. Chem., v. 35, p. 231, 236.

(3) GREAVES, J. E. 1916 The influence of salts on the bacterial activities of the soil. *In* Soil Sci., v. 2, p. 443–480.

(4) GREAVES, J. E., AND CARTER, E. G. 1920 Influence of moisture on the bacterial activities of the soil. *In* Soil Sci., v. 10, p. 361–387.

(5) GREAVES, J. E., AND CARTER, E. G. 1923 The influence of irrigation water on the composition of grains and the relationship to nutrition. *In* Jour. Biol. Chem., v. 58, no. 2, p. 531–541.

(6) GREAVES, J.E., CARTER, E. G., AND LUND, YEPPA 1921 Influence of salts on azofication. *In* Soil Sci., v. 13, p. 481–499.

(7) GREAVES, J. E., AND NELSON, D.H. 1923 The influence of nitrogen in soil on azofication. Utah Agr. Exp. Sta. Bul. 185.

(8) GREAVES, J. E., STEWART, R., AND HIRST C. T. 1917. Influence of crop, season, and water on the bacterial activities of the soil. *In* Jour. Agr. Res., v. 9, p 293.

(9) HARRIS, F. S. 1916 The irrigation of wheat. Utah Agr. Exp. Sta. Bul. 146.

(10) HARRIS, F. S., AND PITTMAN, D. W. 1919 The irrigation of oats. Utah Agr. Exp. Sta. Bul. 167.

(11) HARRIS, F. S., AND PITTMAN, D. W. 1922 The irrigation of barley. Utah Agr. Exp. Sta. Bul. 178.

(12) HIRST, C. T., AND GREAVES, J. E. 1920 Some factors influencing the quantitative determination of chlorides in soil. *In* Soil Sci., v. 9, p. 41–51.

(13) HIRST, C. T., AND GREAVES, J. E. 1924 The influence of manure and irrigation water on the carbon, phosphorus, calcium, and magnesium of soil. *In* Soil Sci., v. 19, p. 87–97.

(14) MONNIER, A., AND KRECZYASKI, L. 1917 The use of iron in agriculture. *In* Arch. Sci. Phys. et Nat. [Geneva], v. 43, no. 1, p. 66–68. *Abs. in* Exp. Sta. Rec., v. 38, p. 727.

(15) Official and Tentative Methods of Analysis of the Association of Official Agricultural Chemists. 1919. Washington, D. C.

(16) OSBORNE, THOMAS B. 1907 The proteins of the wheat kernel. Carnegie Inst. Washington Pub. 84, p. 119.

(17) PETERSON, W. H. 1914 Forms of sulfur in plant materials and their variation with the soil supply. *In* Jour. Amer. Chem. Soc., v. 36, no. 6, p. 1290.

(18) PETIT, P. 1892 Distribution and form of iron in barley. Compt. Rend. Acad. Sci. [Paris], v. 115, no. 4, p. 246–248. *Abs. in* Exp. Sta. Rec., v. 4, p. 301.

(19) PETIT, P. 1893 The influence of iron in soil on the growth of barley. *In* Compt. Rend. Acad. Sci. [Paris], v. 117, p. 1105–1107. *Abs. in* Exp. Sta. Rec., v. 5, p. 1094.

(20) SHERMAN, HENRY C. 1918 Chemistry of Food and Nutrition. Macmillan Co., New York.